Biomass Energy Systems

Proceedings of the International Conference
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Foreword
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Note. Please note that only the addresses of the first authors are given in the respective papers. The addresses of the co-authors are appended at the end of the book.

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FOREWORD

A large part of the human race on this planet still uses biomass as a source of energy. Yet, this is perhaps the one segment of energy problems that suffers universally from continuing neglect. Problems of growing scarcity of biomass in different parts of the world, harmful environmental pollution resulting from burning of biomass, and issues related to inappropriate land use, all add urgency to the challenge faced in building sustainable and environmentally sound energy systems revolving around biomass forms.

The proceedings contained in this volume represent a comprehensive treatment of each element of the biomass energy system, ranging from questions of forest management and forestry science to those dealing with technologies that hold the potential for bringing about major improvements in the efficiency of use of biomass energy. The coverage also extends to biomass that is produced from consumptive lifestyles and the generation of organic wastes in large metropolitan areas as well. Traditionally, biomass energy has been associated only with its use in rural areas. However, now that large urban centres face a major problem in disposal of municipal solid waste, opportunities arise from large concentrations of organic materials, which can be converted into useful energy. Technologies and business opportunities have evolved in this regard to make biomethanation a serious option not only in the clean up of solid wastes in urban areas, but also in producing energy in an environmentally friendly manner.

This volume would be a very useful reference document for anyone who would like to be acquainted with the state-of-the-art in respect of biomass energy systems as they exist today and as they can be improved on in the years ahead. It is indeed very heartening that these proceedings come out as the contribution of a large number of serious professionals and the collaborative endeavour of organizations that are dedicated to the achievement of sustainable use of natural resources.

R K Pachauri
Director, TERI

PREFACE

Biomass has traditionally been the most important source of energy in rural areas and a major fuel even in the urban areas. In spite of rapid increases in the supply of, and access to, fossil fuels, biomass is likely to continue to play a dominant role in India, as it is in many other developing countries, in the foreseeable future. Thus, developing and promoting techno-economically viable technologies to utilize biomass in an efficient manner is of high priority. This was the main focus of the *International Conference on Biomass Energy Systems* held on 26–27 February 1996 at New Delhi, which was jointly organized by the Tata Energy Research Institute, New Delhi, and the British Council Division of the British High Commission in India. The conference had over 100 participants, including research scientists, academicians, policymakers, programme implementors, entrepreneurs, multilateral funding agencies and voluntary organizations. An international perspective had been lent to the conference by participation from the United Kingdom, Nepal, Sri Lanka, Pakistan, Switzerland, and Myanmar. This diversity in participation is adequately reflected in the papers presented in this volume.

These proceedings contain 50 papers grouped into seven sections. The first section covers issues relating to the production, supply, and demand of various biomass sources, and also the policies for biomass management. Section II is devoted to biomass processing for fuel purposes, including conversion to liquid fuels. Sections III, IV, and V deal with various aspects of biomass gasification, improved cookstoves, and biogas technology, respectively. The sixth section contains papers on the fast-growing subject of biomethanation of municipal solid wastes. Lastly, Section VII looks at biomass-based power generation including cogeneration at sugarmills. The papers in various sections range from highly technical to application-oriented to location-specific case studies. Thus, an attempt has been made to provide a comprehensive coverage of all the major issues pertaining to biomass energy. These proceedings are expected to be of relevance to all the stakeholders in the biomass energy sector.

Venkata Ramana P
Srinivas S N

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Several people and organizations have made this volume possible. Firstly, we would like to express our sincere gratitude to the British Council Division (BCD) of the British High Commission who not only collaborated in organizing the conference but also provided financial support. The technical and organizational inputs provided by Mr Raj Gupta and Mr R Dinakar of BCD were critical. The Indian Renewable Energy Development Agency (IREDA) and Renewable Power Projects Limited (RPPL), Gujarat, extended partial financial assistance.

At TERI, a number of colleagues made substantial contribution to the conference as well as the proceedings: Ms Meena Srikumar took the overall charge of bringing out the proceedings; Mr T Radhakrishnan and Ms Anshu Sharma were responsible for the design and layout of the book; Mr R K Joshi did all the graphics; copy-editing inputs were given by Mr K P Eashwar, Ms C V Indira, Ms Anitha Saravanan and Mr Anil Verma; Ms Poonam Deveshwar diligently wordprocessed all the papers; and Ms Pratibha Shukla provided technical assistance. Colleagues in the Rural Energy, Forestry, and Renewable Energy groups have helped at various stages. The constant support and encouragement given by Dr R K Pachauri, Director, TERI, is gratefully acknowledged.

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Section I

Biomass supply and demand, and policy issues

FORESTS AS BIOMASS ENERGY RESOURCE IN INDIA

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Introduction

Since the beginning of planned development in India, substantial budget allocations have been made for the development of commercial sources of energy. Due to this, the non-commercial energy component declined from 74% in 1950/51 to about 40% in 1993/94 (TERI 1996). Nevertheless, nearly 75% of the rural population of India is still dependent on biofuels (firewood, agricultural residues, and cowdung) for meeting over 80% of their energy needs. Similarly, the urban poor, including slum dwellers, who constitute 25–30% of the urban population, are heavily dependent on biofuels. Further, the inability of the rural people to shift to commercial fuels like liquefied petroleum gas (LPG) and kerosene, on account of their low purchasing power and the limited availability of these fuels, has increased the dependency of the rural population on biofuels considerably. Nearly 44% households in urban areas have reported that kerosene supply from the public distribution system (PDS) was inadequate (TERI 1996) LPG supply, which is already in short supply, is confined to major towns and cities. Also, the price tag on this fuel puts it beyond the reach of the common man Again, although about 85% of total villages in the country were electrified by 1994/95, supply of electricity is very erratic and uncertain; emphasis having been given to irrigation, small-scale industries, and lighting in the successive Five Year Plans.

Unfortunately, availability of biofuels, particularly fuelwood, is rapidly decreasing due to the rapid degradation of the resource base – a result of the sharp increase in human and livestock population which has built up tremendous pressures on our natural resources, and at several places, has already assumed crisis proportions. During the period

1951–1990, forest cover on village common lands and forest lands decreased by more than 30 million hectares (mha). Over 165 mha (about 54% of the geographical area of the country) were under agriculture in 1990/91 and 68 mha under forests (MoA 1994).

Exponential rise in both human and livestock population, agriculture, and various developmental activities are critical factors behind the shrinkage of vegetal cover. India's human population has more than doubled during the period 1951–1991 – from 361 to 853 million (Premi 1993); the total livestock population increased from 292 to 445 million during the same period – the increase in goat population being rather steep, i.e , from 47.08 million in 1951 to 110.21 million in 1991 (MoA 1993; MoA 1995). Due to the expansion of the cultivated area to more and more marginal lands, people's dependence on forests has also increased

Local communities have rights and concessions in the forest areas to collect fuelwood for their own consumption and the firewood gathered by them is never recorded. Similarly, due to acute unemployment and grinding poverty, four to five million people have taken to 'headloading'. The entire quantity of fuelwood taken out by them goes unrecorded.

Rapid urbanization has also affected land use. Urban population, as fraction of total population, has increased from 11% in 1901 to 25.72% in 1991 (GOI 1991) It is estimated that by 2010, India will have an urban population of nearly 392 million living in towns and cities constituting about 33.8% of the total population. Fertile agricultural land becomes the first casualty of urbanization and industrialization.

The problem of scarcity has been aggravated by the steep rise in fuel prices in urban areas, particularly fuelwood, putting a heavy burden on the poor, as energy forms the bulk of their expenditure. According to one estimate, nearly 37% of total non-food expenditure goes towards energy in the lowest income class, as compared to the 9% in the highest income class (TERI 1996). While the average retail rural prices of fuelwood on an all-India basis increased at the rate of eight per cent per annum between April 1984 to April 1989 (CMIE 1988), the annual rate of increase in retail fuelwood prices between April 1978 to April 1987 has been 12.6% in Calcutta, 14.9% in Delhi, 9 3% in Madras, 12.6% in Bangalore, and 11% in Hyderabad (CMIE 1988).

Deteriorating fuelwood supply due to an eroding resource base is manifested in the impacts on rural lifestyles and quality of life. The increase in time and travelling distance for women and children, who collect bulk of the fuelwood, is nothing short of a drudgery; the time spent and the distance travelled by them for fuelwood gathering varying from 4–5 hours and 4–10 km per day respectively (TERI 1995). In most rural areas, especially in the hilly regions, women usually participate in both economic and non-economic activities, and increased collection time has a high opportunity cost which is difficult to quantify. This increased burden has a deleterious effect on the health of women and education of children.

Firewood consumption

Although a large proportion of rural domestic energy is supplied by biomass fuels, which include fuelwood, branches, twigs, and leaves (collectively termed as firewood in this pa-

per), it is mostly collected at a zero private cost from all types of areas (forests and other public lands, *panchayat* lands, roadsides, along railway lines and canals, private farmlands, and home gardens/homesteads) both for personal consumption as well as for sale. Firewood is also obtained from operations like fellings, cleanings, thinnings, pruning, and pollarding from forests, horticultural areas, and farmlands, and illicit removals from forest areas and other public lands. Again, in the scarcity-hit pockets, local weeds and shrubs are also collected. Because of these reasons, reliable estimates of firewood consumption are hard to obtain.

Major efforts for stipulating energy requirements of the country were made by the Energy Survey of India Committee (1965), the Fuel Policy Committee (1974), the Working Group on Energy Policy (1979), the Advisory Board on Energy (ABE 1985), and the Energy Demand Screening Group (1986). All these studies, except that of the ABE, based their recommendations on the National Council for Applied Economic Research (NCAER) surveys conducted in 1958–60 which indicate energy requirement levels of 510 kcal per capita per day (Joshi, Sinha 1993) Based on per capita consumption, population growth, economic development, as well as the availability of alternative sources of energy, various estimates of consumption and demand projections for fuelwood have been made in India. Two of these estimates are indicated in Table 1.

The Report of Working Group on Minimum Domestic Cooking Energy Requirement for Rural Areas with Special Reference to Firewood (1989) estimated the total demand of firewood in the country as 272.4, 296.2, and 377 4 million tonnes (mt) in 1987, 1990, and 2000 respectively (NWDB 1989). The Study Group on Fuel and Fodder, set up by the Planning Commission, has estimated fuelwood demand during 1991, 1996, and 2001 as 306.4, 342.8, and 383.6 mt (PC 1990). Based on 1991 census, the Tata Energy Research Institute (Joshi, Sinha 1993) has placed the firewood requirement for rural domestic sector at 252.1 mt. Dwivedi (1994) has calculated a total firewood consumption of 265 mt in 1991, of which 39 mt was consumed in urban areas. Kishore, Joshi (1995) have worked out the fuelwood consumption of rural and urban households to be of the order of 168.7 and 23.8 mt respectively in 1995 This estimate does not take into account the consumption of fuelwood by hotels, *dhabas* (roadside eating places), hostels, sweetmeat shops, etc.,

TABLE 1
Estimated demand/consumption of fuelwood

Year	Estimated demand/consumption of fuelwood (million tonnes)	
	1[a]	2[b]
1985	133.30	154 00
1989	146.30	—
1990	—	165.14
1995	—	176.28
2000	163.00	187 42
2005	—	198.56

[a] Natarajan (1996); [b] Kaul (1993).

in cities and towns and various rural industries, and village applications which should be not less than 10% of the total fuelwood consumption. In addition, about 3 mt of fuelwood is required for use in crematoria alone.

There have, however, been several local surveys which indicate per capita annual consumption of fuelwood in various states in the country (Tables 2 and 3).

Table 2
Annual consumption of fuelwood in selected states

State	Year	Annual consumption (mt)
Andhra Pradesh[a]	1995	17.29
Gujarat[b]	1990	7.37
Jammu & Kashmir[c]	1987	27.85
Karnataka[d]	1987	19.39
Kerala[d]	1993	11.63
Punjab[e]	1993	28.38
West Bengal[b]	1990	12.21

[a] Reddy (1994); [b] GOWB (1991); [c] GOJK (1987); [d] Goswami *et al.* (1995); [e] Singh, Dhanda, Singh (1993).

Table 3
Per capita fuelwood consumption in various states

State	Average per capita consumption of fuelwood/annum (kg)
Arunachal Pradesh (kg/capita/day)[a]	3.1–10.4
Assam (kg/capita/month[b]	22–64
Haryana (Aravallis)[c]	287
Himachal Pradesh[d]	523
Jammu & Kashmir[e] (496 kg in rural areas and 180 kg in urban areas) (kg)	430
Karnataka[f] (rural 551 and urban 140)	420
Kerala[g]	570
Meghalaya[h] (kg/capita/day)	2.1–4.7
Nagaland (kg)[i]	399 (rural areas) 364 (urban areas)
Punjab (kg)[j]	192
Rajasthan[k]	292
Tamil Nadu[l]	591
Uttar Pradesh (Tehri-Garhwal)[m]	500

[a] Maikhuri (1991); [b] Ramana, Kukrety (1993); [c] Srivastava, Kaul (1995); [d] Singh (1993); [e] GOJK (1987); [f] Ranganthan, Subha Rao (1987); [g] Goswami *et al.* (1995); [h] Maikhuri, Gangwar (1992); [i] NCAER (1987); [j] Singh, Dhanda, Singh (1993); [k] Ahuja, Rathore (1987); [l] Dhanpal (1992); [m] Gairola (1993)

The availability of dung has not increased significantly, and the increasing crop residues have not been able to keep pace with the growing demand for energy in the villages. Consequently, the demand for firewood has increased rather rapidly. Whereas fuelwood constituted about 54% of the total rural household energy in 1978/79, it increased to 62% in 1992/93; most of the firewood used being collected rather than purchased (Natarajan 1996).

Tables 2 and 3, and the demand/consumption estimates of various committees, indicate that the consumption of firewood in the country is quite high (about 300 mt per year) which is going to increase in the foreseeable future.

Of the 76 77 mha officially recorded as forest (23.25% of the total geographical area), 41.49 mha is reserve forest, 22.97 mha protected forest, and 12.23 mha unclassed forest (FSI 1995), with tenuous government control over protected and unclassed forests. The unclassed forests are undemarcated, heavily encroached upon, and ownership in many states is under dispute. In the north-eastern states of the country, most of the forest areas are unclassed, with no specific legal status, or are under private ownership. As much as 91.5%, 75.05%, and 63.4% of forest area in Meghalaya, Arunachal Pradesh, and Manipur, is unclassed, while 88.35% of Nagaland forests are under private ownership (FSI 1987). As a result, no scientific management has been possible in most of these unclassed forests.

The extent of officially recorded forest area does not reveal the actual position, as the figures indicate, in as much as the latest assessment (1993) based on satellite data shows that the land area under *actual forest cover* is of the order of 64.01 mha or 83.4% and 19.5% of the recorded forest area and total geographical area of the country. Of the total actual forest cover 38.6 mha (11.73%) constitute dense forest cover (crown density 40% and above), 25 mha (7.61%) as open forest cover (crown density between 10% and 40%), and 0 43 mha (0.13%) as mangroves (FSI 1993). The average per capita forest area is 0.09 and 0.08 ha for the recorded and actual forest cover, respectively, though these figures vary with different states; Arunachal Pradesh has the highest per capita forest area of 7.94 ha

The total exploited or potentially exploitable forests in the country account for about 66% of the recorded forest area, while the remaining 34% are either grasslands, unproductive, inaccessible, or required to be maintained for protection purposes.

Considering the actual forest cover of 64.01 mha, 10 mha is managed as protected forest for ecological stability, 16 mha for production of timber, 25 mha as social forest to meet the demand of fuelwood and fodder, while national parks and wildlife sanctuaries cover an area of nearly 13 mha (FSI 1987).

The growing stock per ha of the actual forest cover (64.2041 mha – 1987 assessment) in Indian forests varies from as low as 10 m^3 in Rajasthan (northern region) to as high as 277 m^3 in the coniferous forests of Kulu valley (northern region); the average growing stock being about 74 m^3 per ha which compares poorly with the world average of 110 m^3 per ha. The total estimated growing stock of wood in the country is placed at 4740.86 million cubic metre (mcm) with a mean annual increment of 87.62 mcm or 1.85% of the total growing stock (FSI 1995). Considering the recorded forest area of the country (76 77 mha), the average annual increment of 87.62 mcm works out to 1.14 m^3 per ha which is much lesser than the world average of 2.1 m^3 per ha. Similarly, in terms of both growing stock and increment, India is behind the developed world.

The potential productivity of the forests of the country is, however, much higher than the actual production. On the basis of Paterson's productivity index, the potential productivity of Indian forests has been estimated to be around 490 mcm per year (Seth, Kaul, Sharma 1972). However, the actual productivity ascertained by the Forest Survey of India (FSI), in forests reasonably protected from biotic influences, shows that the annual productivity per ha may vary from 0.41 m^3 in the dry forests of the Indus plains to nearly 4 m^3 on the west coast and the Andaman Islands. On the basis of field inventories carried out by FSI, it is reported that India's forests are not capable of producing more than 90 mcm of wood, annually, because of their existing state. This figure is about three times greater than the current annual average recorded production of 30 mcm. In fact, the annual production of wood in any year since the beginning of scientific forest management in India has not exceeded 32 mcm (FSI 1987).

The total annual increment of forests in the country is estimated at 87.6 mcm. With 26 mha as degraded forests (with a crown density of less than 40%), it is but reasonable that only 50% of this increment be harvested and the remaining 50% be utilized for improving the condition of the crop. Sustainable availability of wood from the forests thus stands at 43.8 mcm. Presuming that 80% of this constitutes fuelwood, the total sustainable fuelwood available from the forests would be about 35.0 mcm (24.5 mt).

Nearly 20 mha of plantations have been raised so far (1992/93) on both public and private lands. Of the total area afforested, nearly 50% was planted under various developmental programmes of social forestry, farm forestry, agro-forestry, etc., primarily for fuelwood.

The forest area diverted for various non-forestry purposes during the period 1952 to mid-1993 is of the order of 4.6 mha, with 0.116 mha having been lost annually, on an average. The impact of agriculture on the denudation of forests has been the maximum as exemplified by the diversion of the largest forest area (2.6 mha) to agriculture between 1952 and 1980 (MoEF 1987, Dhamija 1993). In fact, agriculture has always expanded at the expense of forests and large areas have been cleared frequently in the past and released for agriculture. It is reported that nearly 0.7 mha of forest land was encroached upon between 1951 and 1982 (MoEF 1987) The total forest area affected by shifting cultivation is around 5 mha with an annual area of 1 mha under this practice, implying a shortening of the crop-fallow cycle to five years, which is rather detrimental to the recovery of the *jhum* areas to forest cover. It has been estimated that during the period 1981–90, the average rate of deforestation in the country was 0 34 mha per year, i.e 49 500 ha in the tropical rain forests, 37 800 ha in moist deciduous forests, 214 100 ha in dry deciduous forests, 2100 ha in desert zones, and 35 500 ha in hill and mountain zones (FAO 1992).

It is reported that over 100 million heads of livestock (53 million cows, 22 million buffalos, 25 million goats and sheep or 110 million cow units graze in the forests of the country (MoEF 1989). Considering the degraded state of the forests and a minimum requirement of 2 ha of land per one cow unit, the grazing pressure on the forests is more than three times, far beyond the carrying capacity of this resource

Occurrence of frequent fires is a major cause of injury to the forests, particularly to regeneration While some fires are incidental, majority of them are incendiary, deliberately caused either to get new shoots of grass or leaves (*Diospyros*) or to facilitate collection of

forest produce like *Mahua* and *Sal* seeds. It is reported that the forest area subject to annual fires varies from 33% in West Bengal to 93% in Arunachal Pradesh (FSI 1987).

Excessive grazing, frequent fires, and other biotic factors have adversely affected the natural regeneration of our forests to a considerable extent. Inventories carried out by FSI, in a few representative localities, indicate that except in Andaman and Nicobar Islands, natural regeneration is either absent or inadequate in 52 8% of the forest area of the country. These results, though only indicative, nevertheless point to an alarming situation Concerted and determined efforts have to be made to eliminate the damaging biotic factors to allow these forests to regenerate naturally

Fuelwood production

Production of fuelwood in India is reported by the Centre for Monitoring Indian Economy (CMIE) to be 129.43, 141.75, and 108.21 mt during 1972/73, 1977/78 and 1983/84, respectively (CMIE 1990) Similar estimates for the period from 1982 to 1993 as given by FAO (1995) are indicated in Table 4

The production figures (July 1990) reported by CMIE are based on the recorded production of the state forest departments, as also the unrecorded extraction worked out by multiplying the recorded production by a factor of 10 This appears to be very much an underestimate, as studies conducted in a few states show that unrecorded production of fuelwood is 17–22 times that of recorded production (Dwivedi 1994). Further, these production figures do not take into account off-cuts, sawdust, and leaf biomass being used as firewood.

In many states, farmers have taken to tree cultivation in a big way and substantial quantities of fuelwood are being produced and sold in the market from private sources. A study conducted by the Institute of Development Studies (Ahuja, Rathore 1987), indicates that 6000 quintals of wood enter Jaipur city every day, mostly by camel carts, within a radius of 100 km Substantial quantity of firewood is contributed by weeds like *Lantana camara*, *Ipomoea carnea*, etc Table 5 shows the possible supply of firewood worked out for different categories of lands in the country In addition, 24.67 mcm of round timber excluding fuelwood was produced in India during 1993 (FAO 1995), of which a minimum of 20% would be in the form of off-cuts and sawdust Taking 50% of these off-cuts and sawdust being used as fuel, particularly in rural industries and other applications, the availability of firewood from these two sources is around 1 7 mt.

TABLE 4
Estimated production of fuelwood in India

Year	Fuelwood and charcoal (mcm)
1982	210.78
1985	224.70
1990	248.02
1991	252.87
1993	262.78

TABLE 5
Estimated supply of firewood from various land use categories in India

Land use category	Area (mha)	Possible supply of firewood (mt)
Agriculture	157.70	82.70
Wastelands	15.00	15.00
Fruit trees and woody cash crops	7.90	11.30
Miscellaneous tree crops	3.70	3.70
Pastures and grazing lands	11.80	5.90
Canals	0.06	0.12
Railway lines	0.07	0.14
Roads	1.68	3.36
Homesteads/home gardens	5.00	15.00
Sub-total	202.91	137.22
Forests	67.99	163.90
Total	270.90	301.12

Shrubs and weeds

Due to the acute scarcity of firewood in several parts of the country, a large section of the population is meeting its cooking and heating energy needs from shrubs and weeds. *Crataegus crenulata, Berberis species, Rhus parviflora, Olea cuspidata, Lantana camara,* and *Wood fordia fruticosa* are extensively used in the hilly regions of Himachal Pradesh and Uttar Pradesh. *Ipomoea carnea, Adhatoda vasica, Balanites aegyptiaca, Capparis aphylla,* and *Vitex negundo* are gathered in the plains of Uttar Pradesh, Madhya Pradesh, Haryana, and Orissa. *Parrotia* in Kashmir, *Calligonum polygonoides, Ziziphus xylopyra, Z. mauritiana, Calotropis,* and *Crotolaria* in Rajasthan, and *Gliricidia sepium, Cassia auriculata,* and *Cleistanthus collinus* are the main shrubs used for fuel in Southern states. In many localities, *Butea monosperma*, due to repeated hacking, has become shrubby. In the semi-arid and arid regions of the country, *Prosopis juliflora* has been extensively planted. Its shrubby form has aggressively engressed many wastelands, road sides, and even the stretches along the water courses in many states, and has become a major source of fuelwood in parts of Haryana, Punjab, Uttar Pradesh, Rajasthan, Gujarat, Maharashtra, Andhra Pradesh, and Tamil Nadu.

During the last two decades many families in Andhra Pradesh and Tamil Nadu have found a major occupation base in *Prosopis juliflora*. It is estimated that 37% of fuelwood in rural areas of Tamil Nadu was contributed by *Prosopis juliflora* in 1985 while its share was 35% in Rajasthan (SSFRD 1994; Ahuja, Rathore 1987). However, many weeds and shrubs like *Ipomoea, Euphorbia, Calotropis, Eupatorium,* and *Opuntia* are inferior fuels and pose health hazards While due to thorns and spines, the cutting and collection of *Prosopis juliflora, Balanites, Lantana camara,* and *Opuntia* are difficult, the repeated hackings of shrubs like *Calligonum polygonoides* and *Parrotia* have made them scarce. The availability of air-dried biomass from shrubs and weeds varies from 1 to 6 tonnes per ha per annum, depending upon the site.

Fuelwood resource development

Shortage of firewood became apparent in some parts of the country by the end of the nineteenth century when a need for fuelwood programme was felt. In 1893, Voelcker's report on Indian agriculture suggested creation of fuel and fodder reserves to supply small timber, wood for implements, and firewood, leaves, and grass to agricultural communities which was included in the Government of India's forest policy resolution of 1894 (Lal 1989). The National Planning Committee, in its report submitted in 1948, considered the problem of soil conservation through afforestation and stated that lack of forests within the easy distance of most of the problem districts had resulted in the enormous waste of the only source of cheap manure by burning cowdung (Dwivedi 1994). Because of the revolutionary changes since 1894, India's forest policy was revised in 1952 (Lal 1989), wherein a functional four-fold classification of forests into protection, national, village forests, and tree lands was proposed. It stipulated progressively increasing supplies of fodder, timber for agricultural implements, and firewood to spare cattle dung for use as manure. The First and Second Five Year Plans focused attention on planting economically important species, while the Third Five Year Plan for the first time aimed at self-sufficiency in both industrial and fuelwood with a thrust on plantation of quick-growing species Only 2.2% of the total allocation of the forestry sector was spent on the farm forestry-cum-fuelwood scheme during the period 1951–69 (Dwivedi 1994).

The first major document on fuelwood was produced in 1973 by the National Commission on Agriculture (NCA) in its interim report on Social Forestry (Dwivedi 1994). It stated that farm forestry was aimed at the production of fuelwood and small timber only to some extent and emphasized that adequate steps had not been taken to augment fuelwood resources. It also called for a national effort to achieve its objectives (listed below).

- Fuelwood supply to the rural areas and replacement of the cowdung
- Small timber supply
- Fodder supply
- Protection of agricultural fields against wind
- Recreational needs.

The urgency of the situation was underlined in 1974 by the Report of the Fuel Policy Committee which stated that

> ... nearly one-half of the total energy consumed in the country comes from noncommercial sources such as firewood (including charcoal), cowdung, and vegetable waste. The dependence on these fuels is maximum in the domestic sector.

The Fifth Five Year Plan adopted the recommendations of the NCA's interim report on both production as well as social forestry. In 1976, the Commission, in its report on the forestry sector, called for the revision of 1952 forest policy (NCA 1976). The report on the Working Group on Energy Policy (1979) supported the adoption of a national social forestry programme (Dwivedi 1994).

The real impetus for augmenting fuelwood supply was given during the Sixth Five Year Plan, when countrywide afforestation and social forestry programmes were launched. A centrally sponsored scheme on rural fuelwood plantations was started in 1980/81 in 101 fuelwood deficient districts, later extended to 157 districts, to grow fuelwood as near as possible to the consumption points. The Planning Commission constituted a Committee to study all aspects of fuelwood including production, consumption, and utilization of by-products, which submitted its report in March 1982 (PC 1982). Some of the major recommendations of this Committee are outlined below.

- Recognition of fuelwood as one of the basic needs of the people and incorporating it in the Minimum Needs Programme.
- Formulation of an integrated policy of land and livestock.
- Estimation of district-wise availability and demand of fuelwood within a 20-year framework and identification of areas for intensive fuelwood production.
- Stepping up of annual fuelwood plantation programme up to about 1 5 mha per year during the next 10 years to meet the projected fuelwood needs, and developing fuelwood farming as a major agroforestry and farming system Fuelwood farming was estimated to require financial support of the order of Rs 8 to 10 billion per annum.
- Initiating a time-bound 10 year programme for covering each village with a minimum of 4 ha of fuelwood plantation on community or government lands in the vicinity of the village entirely at government cost but with people's participation.
- Manufacture of charcoal in kilns of improved designs, use of improved stoves/ *chulhas*, use of wood-saving crematoria, utilization of sawmill and logging waste for briquetting wherever economically feasible, and propagation of community biogas plants in the villages.
- Identification and breeding of suitable fast-growing and coppicing tree species.
- Recognizing that the future strategy for meeting fuelwood requirements lies largely in production from private farmlands of the country, and the establishment of strongly motivated extension wing at the centre
- Promotion of an integrated action plan with appropriate packages of technology, services, and public policies.

For augmenting the production of fuelwood, a social forestry programme was started in 15 states with assistance from the World Bank, and bilateral agencies like the US Agency for International Development, Danish International Development Agency (DANIDA), Swedish International Development Agency (SIDA), Canadian International Development Agency (CIDA), etc The Rural Development Department, Government of India, started employment oriented schemes take the National Rural Employment Programme (NREP), the Rural Landless Employment Guarantee Programme (RLEGP), and area development schemes like the Drought Prone Area Programme and the Desert Development Programme as well. Efforts were also made to popularize the programmes in rural areas particularly among the poorer sections of the community by distributing seedlings free of cost However, the overall success rate of these plantations is unlikely to exceed 30%.

A wasteland development programme was initiated during the Seventh Five Year Plan to deal with the following issues:

- ecological crisis caused by deforestation and land degradation;
- socio-economic crisis caused by acute shortage of fuelwood and fodder, and
- making afforestation a peoples' movement.

The National Wastelands Development Board (NWDB) was established in May 1985, with the mandate of developing wastelands through a massive programme of afforestation and tree planting with peoples' participation. In order to foster a people's programme, decentralized people's nurseries, tree grower's cooperatives, dairy cooperatives with the support of the National Dairy Development Board, and farm forestry cooperatives with the support of the Indian Farmers Fertilizers Cooperatives were established.

One of the basic objectives of the National Forest Policy (1988) is to meet the requirements of fuelwood, fodder, minor forest produce, and small timber, of rural and tribal population. The policy states that

> ... provision of sufficient fodder, fuel, and pasture, specially in areas adjoining forests is necessary in order to prevent depletion of the forest beyond the sustainable limit. Since fuelwood continues to be a predominant source of energy in rural areas, the programme of afforestation should be intensified with special emphasis on augmenting fuelwood production to meet requirements of the rural people.

Further, a massive need-based and time-bound programme of afforestation and tree planting, with particular emphasis on fuelwood and fodder development, on all degraded and denuded lands in the country, both forest and non-forest, has been emphasized.

The Integrated Rural Energy Planning Programme (IREP) was initiated by the Rural Energy Cell of the Planning Commission in the Seventh Five Year Plan, and 650 blocks were covered by 1995/96 under this programme. However, the involvement of potential beneficiaries at the grassroots level, in the planning and supply of different energy sources and technologies, is still limited and needs to be strengthened During the Eighth Five Year Plan, IREP aimed to focus on two major areas:

- provision of energy for meeting the basic needs of cooking, heating, and lighting by utilizing locally available energy sources; and
- provision of energy as a critical input in the economic development of the rural areas.

The Government of India has created a full-fledged Department of Wastelands Development under the Ministry of Rural Development. The NWDB and National Landuse and Wastelands Development Council have been brought under this Department while the National Afforestation and Eco-development Board has been established in the Ministry of Environment and Forests for the development of wastelands in forest and adjoining areas.

Increasing biomass energy

Presently, the problem of firewood is tackled by the over-cutting and hacking of the vegetation, floor sweeping for collection of leaves, and transporting of fuelwood over long distances to the places facing shortages. The latter not only adds to the price of fuelwood but also wastes energy, mostly diesel which is imported and subsidized, in transport. Supply of biofuels can be substantially augmented by taking the following measures.

Database

There are no reliable data either for the consumption or for the supply of biofuels. Estimates vary widely and are based on scanty surveys. There is, thus, an urgent need for estimation of present availability and demand of the biofuels for each district in the country under a time-bound programme to be completed during the next two to three years to find out the pockets of acute scarcity of fuelwood. This will help in the proper planning and execution of the rural energy programme which needs special focus.

Increased productivity

The present productivity of forest areas and the village's commons is very low. This could be increased by two to three times if the areas under fuelwood plantations are effectively protected from grazing and fires are eliminated, floor sweeping and lopping are stopped and quality planting material is used.

Tree improvement

The main species being planted for fuelwood in the country are *Acacia auriculiformis, Acacia nilotica, Acacia tortilis, Casuarina equisetifolia, Cassia siamea, Eucalyptus*, and *Prosopis juliflora*. These species will continue to be extensively planted in future as well. There is an urgent need to take up selection and tree improvement of these species for finding out high-yielding varieties and cultivars for different agro-climatic regions and developing their cloning methods to get uniform planting material from the best stock.

Urban energy needs

It is estimated that over 40 mt of fuelwood is being used in urban areas, which is likely to increase substantially with the increase in the rate of urbanization. Concerted efforts are needed to reduce/replace firewood use in urban areas with other alternative sources of energy like electricity, soft coke, kerosene, LPG, etc. A proper mechanism will have to be worked out to make available these alternative fuels to the urban poor and slum dwellers at reasonable and affordable prices.

Briquetting

Briquetting of coal and agricultural residues like mustard, sesamum, straw, etc., needs to be taken up on a large scale and the use of briquettes to be popularized among urban and semi-urban commercial establishments like hotels, restaurants, *dhabas*, etc.

Biogas and improved chulhas

Though targets for biogas and improved *chulhas* have been enhanced considerably during the Eighth Five Year Plan, more than chasing targets, implementation of both these

national programmes with proper planning, careful selection of models for a particular area, and quick solutions to the technological problems is essential. Haryana, Punjab, and those areas of the Gangetic plains should get priority in establishing biogas plants where cattle are stall-fed and fodder is cultivated. We may otherwise save fuelwood but degrade forests and village commons through excessive grazing and lopping of trees to feed the animals to get dung. With four to five animals required to feed a family-size biogas plant of 2 m^3 capacity, nearly 8–10 ha of land are required for the grazing of these animals. Availability of adequate water is another crucial factor for establishing biogas plants.

Agro-forestry and farm forestry

An estimated 45–60 mha of land which is unfit for agriculture needs to be brought under perennial vegetation by practising agro-forestry, farm forestry, agri-silvipasture, horti-silvipasture, silvi-pisciculture, etc. The culturable wastelands which at present are the focus of various kinds of erosion, need to be made productive.

There is tremendous potential for farm forestry and agro-forestry in the semi-arid and arid regions and in the north-eastern states. Efforts need to be made to bring areas of *jhum* cultivation under farm forestry and agro-forestry. Fuelwood cultivation could become an economic proposition in these states if it is converted into charcoal and transported to deficit areas.

Management of weed-infested areas

Large tracts of forest areas and other public lands are degraded and infested with weeds like *Lantana, Eupatorium, Carissa, Adhatoda, Euphorbia,* etc. Such lands need special attention for making them productive and useful. Similarly, large areas of arid and semi-arid regions are covered with the shrubby form of *Prosopis juliflora.* Due to periodic hacking, it produces more shoots with bigger thorns, with the result that not only the productivity of such areas declines, but also quality of fuel goes down. By adopting proper management practices and felling cycles, the productivity of such lands can be considerably increased.

Increased outlay

It is pertinent to point out here that so far forestry has worked on the principle of minimal inputs, with barely acceptable results, which is illustrated by the very meagre allocations for forest development under the successive Five Year Plans. Development expenditure under the forest sector, as compared to total public sector investment since the First Five Year Plan through the Eighth Five Year Plan, has only marginally increased from 0.39 to 0.94% Substantial amounts used to be allocated under the employment generation schemes of NREP and RLEGP of the Ministry of Rural Development, where 25% of the total allocation under these schemes was to be earmarked for afforestation works. But with the merger of NREP and RLEGP into the *Jawahar Rozgar Yojana*, without the earmarking of funds for afforestation, there has been a big drop in resource availability; it was only 8.7% in 1989/90, 4.9% in 1990/91, and, at present, just 3%. There is a great need to link up rural energy needs with rural development and enhancing the allocation to at least 5–10% of the total allocation of the energy sector.

Conclusion

While a number of broad measures for augmenting the supply of biofuels have been suggested, a real dent in the crisis situation of biomass availability can only be made when we are able to tackle the burgeoning population of poverty-stricken unemployed people by providing them gainful employment elsewhere, besides having a viable national grazing and fodder policy. It is now clear that forests play a very decisive role in the economic, social, ecological, and environmental health of nations. They also have a pivotal role in meeting the energy needs and increasing agricultural production. The importance of non-timber forest products in providing employment, incomes, and sustenance to people living in and around the forests and the rural poor is now full recognized. In fact, forests are a vital component of the subsistence economy of these underprivileged communities.

These new and emerging priorities call for reorientation in forest and grazing management policies and development programmes both with regard to the crucial role the forests play in maintaining ecological security and in increasing the resource base and its productivity. Absolutely essential in these reoriented policies will be the effective involvement and participation of local communities (including women) in establishing sustainable forest management systems.

References

Ahuja K, Rathore M S 1987 *Rural energy consumption patterns: a study of north-eastern Rajasthan.* Jaipur: Institute of Development Studies.

CMIE. 1988. *Current energy scene in India.* Bombay: Centre for Monitoring Indian Economy.

CMIE 1990. *Current energy scene in India.* Bombay: Centre for Monitoring Indian Economy.

Dhamija I. 1993 Personal communication

Dhanpal D 1992. Rural energy and the quality of air with special reference to a tribal area in Tamil Nadu. *Energy Environment Monitor* 8(1).

Dwivedi B N. 1994. Fuelwood and other energy supply and demand in rural India. International Workshop on India's Forest Management and Ecological Revival Tata Energy Research Institute, New Delhi.

FAO 1992. Forest resources assessment – 1990. Tropical countries. *Forestry Paper* No. 112. Rome: Food and Agriculture Organization.

FAO. 1995 *FAO Year book: Forest Products, 1982–93.* Rome· Food and Agriculture Organization.

FSI 1987. *The State of Forest Report.* Dehra Dun: Forest Survey of India.

FSI 1993. *The State of Forest Report.* Dehra Dun: Forest Survey of India.

FSI 1995 Extent, composition, density, growing stock and annual increment of India's forest. Dehra Dun· Forest Survey of India

Gairola J 1993 Energy use pattern in five mini-watersheds in Tehri District of the Uttar Pradesh hills *Energy Environment Monitor* 9(2)

GOI 1991 *Census of India.* Series 1. India Paper 2. New Delhi. Government of India.

GOJK 1987 *Wood balance study.* Srinagar. Planning and Development Department, Government of Jammu and Kashmir.

Goswami R, Gopal M, Ogle A J, Thorp G 1995. Forest products, supply, markets and utilization. *Working Paper* no. 1 Kerala State Forest Project. Washington, DC. The World Bank.

GOWB. 1991. *State report on West Bengal forests 1990–91.* Calcutta: Forest Department, Government of West Bengal.

Joshi V, Sinha C S. 1993. Energy demand in the rural domestic sector. *Urja Bharati* **3**(3).

Kaul O N. 1993. Forest biomass burning in India. *In* Achanta A (ed.). *The Climate Change Agenda: An Indian perspective.* New Delhi: Tata Energy Research Institute.

Kishore V V N, Joshi V. 1995. Greenhouse gas emissions from cookstoves. *Energy Environment Monitor* **11**(2).

Lal J B. 1989. *India's Forests: Myth and Reality.* Dehra Dun: Natraj Publishers.

Maikhuri R K. 1991. Fuelwood consumption pattern of different tribal communities living in Arunachal Pradesh in North-eastern India. *TIDE (TERI Information Digest on Energy)* **1**(3).

Maikhuri R K, Gangwar A K. 1992. Fuelwood use by different tribal and non-tribal communities in North-east India. *TIDE (TERI Information Digest on Energy)* **2**(2).

MoA. 1993. *Report of the Technical Committee on Direction For Improvement of Animal Husbandry and Dairying Statistics.* New Delhi: Department of Animal Husbandry and Dairying, Ministry of Agriculture, Government of India.

MoA. 1994. *Agricultural statistics at a glance.* New Delhi: Ministry of Agriculture, Government of India.

MoA. 1995. *Agricultural statistics at a glance.* New Delhi: Ministry of Agriculture, Government of India.

MoEF. 1987. *India's Forests.* New Delhi: Ministry of Environment and Forests, Government of India

MoEF 1989. Environment and development – traditions, concerns and efforts in India. National Report to UNCED. New Delhi: Ministry of Environment and Forests, Government of India.

Natarajan I. 1996. Energy planning at the microlevel - an Indian experience. *Wood Energy News* **10**(4).

NCA. 1976. Report. New Delhi: National Commission on Agriculture, Government of India.

NCAER. 1987. *Reforestation programme for Nagaland.* New Delhi: National Council for Applied Economic Research.

NWDB. 1989. *Report of the Working Group on Minimum Domestic Cooking Energy Requirement for Rural Areas with Special Reference to Firewood.* New Delhi: National Wastelands Development Board, Government of India.

PC. 1982. Report of the Fuelwood Study Committee. New Delhi: Planning Commission, Government of India

PC. 1990. Report of the Study Group on Fuel and Fodder. New Delhi: Planning Commission, Government of India.

Premi M K. 1993. Population, poverty and rural development. *Kurukshetra*: October.

Ranganathan V, Subba Rao S. 1987. *Demand and supply of fuelwood in Karnataka.* Bangalore: Indian Institute of Management.

Ramana P V, Kukrety N. 1993. Natural resources and energy consumption in North-east. *In* Venkata Ramana P (ed.). *Renewable Energy Utilization in the North-east Region: Prospects, problems and strategies.* New Delhi: Tata Energy Research Institute.

Reddy K K. 1994. *The Indian Forester.* **20**(9).

Seth S K, Kaul O N, Sharma D C. 1972. Potential productivity of Indian forests. *In* Golley P M, Golley F B. *Tropical ecology with an emphasis on organic production.* Athens: Institute of Ecology, University of Georgia.

Singh D V 1993 Energy use pattern of rural households in Himalayas: case of Himachal Pradesh *Energy Environment Monitor* 9(1)

Singh K, Dhanda R S, Singh B 1993 *Demand for wood in Punjab*. Ludhiana. Punjab Agricultural University, Department of Forestry and Natural Resources

Srivastava J P L, Kaul R N. 1995. *Fuelwood crisis in the Aravallis: Need for production and conservation* Chandigarh Haryana Forest Department

SSFRD 1994 *Fifth Annual Report 1993/94*. Madras· Society for Social Forestry Research and Development.

TERI 1995 *Environmental considerations and options in managing India's long-term energy strategy*. New Delhi· Tata Energy Research Institute.

TERI. 1996. TEDDY (*TERI Energy Data Directory and Yearbook) 1995/96*. New Delhi· Tata Energy Research Institute.

WOODFUELS UNDER COMMUNITY FORESTRY PROTECTION IN ORISSA, INDIA

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Forests and people in Orissa

Orissa is one of the poorest states of India. Its per capita income in 1991 was only Rs 3180 (Rs 32 = US $1) as against the all-India average of Rs 4974. Orissa has the highest proportion of population below the poverty line, 45% in 1991, as against the all-India average of 30%. Over 87% of the population lives in the rural areas, and is dependent on agriculture and gathering from forest lands as the main economic activities. 40% of Orissa's population is tribal, whose livelihoods and lifestyles are traditionally associated with forests.

In the early 60s, the total forest cover in Orissa was 43% [6.8 million hectares (mha)] of the total geographical area. By 1991, according to the Forest Survey of India, the forest cover had been reduced to 34.8% (5.6 mha). Estimates of the degraded forest area vary from 1 to about 3 mha. Sal (*Shorea robusta*) is one of the most important tree species in the state, with a coverage extending over about 1.7 mha.

For administrative and management purposes, the forests in Orissa are divided into reserve, protected, and village forests (VFs). In 1991/92, the total forest area consisted of 47% reserved (2.61 mha), 28% protected (1.57 mha), and 25% village forest (1.42 mha). Reserved forests (RFs) are fully under the control of the Forest Department (FD) and are managed under various silvicultural systems. All other forests are included within the village boundaries. In protected forests (PFs), only the forest crop (trees) is managed by the FD, while the land is owned and controlled by the Revenue Department (RD) Rights and privileges of the local community vary with the type of forest – restricted in RFs and more liberal in PFs. The VFs are generally treated as open access lands with no investment from the government, and are extremely degraded except where community protection has started.

Fuelwood[1] situation in Orissa

A wood balance study in 1989 shows the source of domestic fuel of rural households (Table 1). RFs and PFs were the main source of domestic fuel, accounting for 76% of the fuelwood and 49% of the brushwood (twigs) used. Next in importance came VFs, which provided 13% of fuelwood, 32% of brushwood, and 15% of dry leaves. Most of the latter (70%) were collected from the roadside.

Nearly 80% of rural households and 15% of urban households in the state were involved in forestry activities, mainly the collection of forest produce for their own use and also collection for sale. The wood balance study estimated that men and women collected forest produce for 149 days in a year. Forestry provided 23% of the income of rural households. About one-third of the households travelled over 5 km for firewood and 2–5 km for brushwood. Only small proportions of the materials used by rural households as fuel were purchased (sales are likely to be more to meet urban demand). Over most of Orissa, the population is finding it increasingly difficult to obtain sufficient supplies of fuel through the traditional means of gathering from the forest. However, the extent to which this has occurred varies considerably from area to area within the state. With forest sources becoming increasingly distant, people turn to using the stems of *Lantana*, *Ipericum*, *Ipomia*, and other shrubs on nearby common and agricultural land; and to such materials as palm fronds, the stalks of such woody stemmed agricultural crops as *dal* (pulses) and pigeon pea, dry leaves, and such non-wood residues as rice and maize stover. Those, such as the landless, who do not need it for their fields, also burn dung. The position of the poor needs to be underlined. Wood is preferred over many of the substitutes they now use, as it burns more evenly, with less smoke than most agricultural residues. Some of the other fuels are also becoming difficult to obtain, and using them as fuel can have opportunity costs for the user. Therefore, if they could obtain increased supplies of fuelwood it would often improve their situation. However, detailed studies elsewhere in India have made it clear that to be

TABLE 1
Share of different fuels in rural domestic fuel consumption

Source	Percentage share in total consumption
Wood and twigs	90.4
Animal dung	2.8
Leaves	3.7
Charcoal	1.1
Crop residues	1.5
Kerosene	0.5

[1] Fuelwood is used here as a collective term for firewood and charcoal, but as charcoal only represents about three per cent of total wood, in round wood equivalent, the term may be generally taken as referring to firewood

used by them, fuelwood supplies must be available at no financial cost. With even minimum food needs usually absorbing all their disposable income, and with the option of shifting to other freely gatherable organic fuels, the poor do not purchase fuelwood. According to the ORG study (1991), domestic cooking constitutes the highest share of firewood consumption in the household sector with an average per capita consumption of 382 kg in rural and 257 kg in urban areas. Paddy boiling is another activity requiring 59 kg of fuelwood per capita in rural areas and 4.8 kg in urban areas. Other household activities requiring fuelwood are space heating, cattle feed preparation, water heating, etc. Considering all the domestic activities, the annual per capita consumption of fuelwood works out to 523 kg and 285 kg in rural and urban regions respectively. Besides social festivals/ceremonies, space heating in village community centres and cremation of dead bodies are the activities at the community level that consume nearly 3.6 kg of fuelwood per capita per annum. The average annual per capita consumption of fuelwood for all the rural artisan activities (like pottery, blacksmithy, brick making, laundry, etc.) is around 15.9 kg. Besides, commercial establishments, hotels, restaurants, tea shops, etc., also use fuelwood at 3.7 kg per capita in rural areas and 4.7 kg in urban areas. Considering all the activities, the per capita consumption of fuelwood in rural areas works out to around 547 kg and 290 kg in urban areas.[2] This would mean a total requirement of about 15 million tonnes (mt) for the entire population, with an estimated annual increase in demand of 300 000 tonnes or 450 000 mm^3.

Estimates for supply are not so reliable. The existing forests, estimated at 5.6 mha together with homesteads and agricultural areas, would produce 15 mt if its productivity for fuelwood alone is 2.8 tonnes per hectare, which, though much above the present level of productivity, is not difficult to achieve. Thus, the impression created by the FD that forests are subjected to severe and increasing pressure due to insatiable demand from the people is not valid. The solutions at the macro level have to be sought primarily in increasing the supply of forest products, rather than on demand management. Therefore, constraints of low productivity and poor supply of forest products of the type wanted by the people and livestock, rather than biotic pressure and increased demand, should be of greater interest to a policymaker if an alternative policy framework to save forests is to be considered. This is not to deny the need for minimizing the rate of deforestation and to speed up the afforestation efforts. At the same time, there is a need to conserve the consumption of fuelwood in the household sector through technological interventions like use of improved *chulhas* and biogas plants. Although facts for Orissa are not available separately, all-India studies show two main trends. One change involves the increasing use of modern forms of energy for productive and household activities, including irrigation pumping and lighting. The second change is that in some areas, rural people, instead of switching up the energy ladder to modern fuels, are moving down to straw, leaves, and twigs. The use of inferior fuels for cooking by rural people have implications for their quality of life. It is also possible that their general purchasing power has gone down. Since 1985, plantations amounting to some 85 000 ha have been established on village/common lands and about 20 000 hec-

[2] A lower estimate has been suggested by the National Sample survey. According to the survey, the per capita consumption in the rural areas in Orissa was only 340 kg of fuelwood.

tares of farm forestry. Yield projections show that approximately 2 m^3/ha of fuelwood can be expected from these plantations annually. This means that the project plantations can contribute 170 000 m^3/year towards fuelwood demand. Even if the total wood production from such lands were assumed to be used as fuel, it would not meet more than one-third of the estimated annual increase in fuelwood demand. But villages are unlikely to use, say, pulpwood grade material as fuel. They will probably continue to collect fuelwood from other sources, mainly from RFs and PFs, for their own use and for sale, and to sell as much as possible of the out-turn from their woodlots.

This underscores the need for producing fuelwood from RFs and PFs through regeneration with people's participation. The necessary policy framework for such initiatives has recently evolved in India through joint forest management programmes (JFMPs). We first describe the government-sponsored Social Forestry Programme (SFP) in Orissa [funded by the Swedish International Development Agency (SIDA)], and then the community inspired protection efforts.

Social forestry in Orissa

The social forestry programme, of planting woodlots on village lands and distributing seedlings to farmers, originated in response to the growing pressure on forests for fuel and fodder needs of the people. The National Commission on Agriculture in 1976 recommended growing trees on lands accessible to village people in order to fulfill their subsistence needs and reduce pressure on forests. The woodlot programme was based on the premise that the initial investment of afforestation would be undertaken by the government, the plantations being later handed over to the village communities for the protection, management, and distribution of benefits. The SFP in Orissa was funded by SIDA in two phases, 1983–88 and 1988–94, with a total budget of Rs 270 million and Rs 783 million respectively. Out of the 13 districts in the state, the project covered nine districts in Phase I, and all the 13 in Phase II. In both phases, the project had four major components.

1. Community-oriented
   - Village woodlots on government wasteland and community land
   - Reforestation and rehabilitation of degraded and depleted forests
2. Individual-oriented
   - Farm forestry on private land
   - Forest farming for the rural poor (FFRP)

Survival

The main activity under the first two components was the establishment of woodlots. A survey was done in 1992 to study woodlot plantations done from 1984 –1988. Plantations already recorded by the Project as non-productive (less than 30% survival, and which

amounted to 32% of the total woodlot area) were not included in the sample. An area was categorized as 'failed' if the basal area of trees was less than 3 m^2/ha, and partly non- productive if the basal area was between 3 and 10 m^2/ha. Year-wise results are given in Table 2.

Based on the field verifications, an average of 37% of the area planted in 1984–88 was regarded as failed and another 21% as partly non-productive. Older plantations, raised in 1984/85, had a higher percentage of non-productive areas compared to younger plantations. The reasons for failures seemed to be combinations of:

- less motivated village communities at the initiation of the plantations, resulting in unsatisfactory protection, grazing and browsing, illicit felling, and, in some cases, even uprooting of planted seedlings at an early stage;
- climatic conditions (like severe drought);
- unfavourable choice of species, rendering some plantations very susceptible to grazing;
- too little extension work by the forest personnel after the initial three years; and
- rivalry between various political groups and neighbouring villages.

The most important reasons were nevertheless grazing and browsing. Large parts of the failed areas have, however, the potential to develop, as the root systems of some constantly browsed, and thus suppressed, planted species are still intact. Natural regeneration of *Acacia auriculiformis* appeared in many cases. However, these sites must be given adequate protection to facilitate survival and development.

It was noticed that success in village woodlots was closely associated with the success of people's participation. Wherever the village protection committees were active and developed their own approaches to protection and benefit-sharing, the plantations had survived. In addition to government-sponsored committees, a large number of indigenous committees have also sprung up in Orissa (these are described later). We shall first discuss the farm forestry programme and then the availability and distribution of fuelwood from government-sponsored projects.

TABLE 2
Survival statistics (area in hectares)

	Year of plantation					Total and percentage (1984–88)
	1984	1985	1986	1987	1988	
Planted	2196	5501	10697	12470	9955	40819 (100%)
Failed	1125	2053	4049	4624	3349	15300 (37%)
Partly non-productive	379	1396	2685	2258	2024	8742 (21%)
Net production	592 (27%)	2052 (37%)	3963 (37%)	5558 (45%)	4582 (46%)	16747 (41%)

Farm forestry in Orissa

Except in the Himalayan and other regions of high fertility and steady rainfall, trees did not form an important component of the farming systems in India. Tree density on farms has declined over the years, the area under privately-owned tree crops and groves falling from 2.77% in 1951/52 to 1.15% by 1980/81. When farm forestry was introduced in the late 70s, with a view to fulfilling subsistence needs of rural households for fuel, farmers in the agriculturally surplus and commercial regions of the country saw, in the programme, an opportunity for substantial cash income as well as considerable savings in terms of labour and supervision inputs. This led to the eucalyptus boom in the early eighties. In subsistence regions such as Orissa, only a few trees were grown primarily to produce goods for use within the family, and in various agro-forestry combinations in which the trees complemented or supplemented other crops rather than replace them. Most farm-level tree cultivation was of a kind which was low-risk, requiring only marginal adjustments to existing farming practices. But the picture was radically different in the agriculturally surplus states, where an increased farm income was the driving force, as the farmers felt that by growing trees they could get a better return on their land, labour, and other inputs.

Constraints in Orissa

The agrarian structure of eastern and tribal India is characterized by the heavy dependence on grain production, smaller holdings, low overall incomes, a less marketed surplus, imperfect credit markets, more dependence on the village merchant for marketing the small surplus, inter-locked credit and output markets, less monetization, less diversity of rural incomes, greater debt bondage, a less developed infrastructure for the supply of agriculture inputs, greater insecurity of land tenure, and, on the whole, poor human capital as far as enterprise is concerned. These conditions can, at best, promote low-intensity tree-growing strategies for home consumption, and are not conducive to market-oriented high- intensity tree planting. Subsistence regions do not accept cash crops easily, and when these are introduced indiscriminately, poor farmers may get affected adversely rather than beneficially. Cases of distress sales by the poor peasants to contractors at a throwaway price a few years before the crop matures are often reported.

Tree growing has been constrained in monocropped India by other factors too. First, young trees require protection from cattle, especially in the fallow season, when the village livestock is let loose to browse agricultural residues and stubbles. During these months in a monocropped village, cattle are generally not accompanied by a herder. On the other hand, in irrigated villages, a tradition is slowly emerging – herding cattle during the cropping seasons. Despite ecological necessity and the easy availability of marginal and degraded lands, protection of young seedlings is difficult in monocropped villages when compared to irrigated villages. Second, most of India's forests are located in areas of backward agriculture. Villages in this region of low productivity often have vast, though degraded, open access lands. Unlike annual crops which are grown on private lands, trees also occur on forest and other public lands. Open access to public lands may vastly reduce the cost of obtaining tree goods for a gatherer, which may work to the disadvantage of a grower. Thus, the concept of trees as a free good, to be obtained from public lands, inhibits

investment of personal labour, land, and capital in tree planting. Proximity to forest lands affects private tree growing in other ways too. The state often restricts farmers' right to freely harvest the trees on private land in the interest of either conservation or of checking theft from forest lands. These create rigidities in the free flow of products. This may make planning of likely income from trees extremely difficult for a farmer. Lastly, if similar products are raised on forest lands, which are marketed through the state machinery, farmers may find it difficult to compete with the state and get a remunerative price, particularly because the traders may be less interested in buying from dispersed producers, and may prefer to deal with the centralized bureaucracy. Evaluation of the first phase of the Orissa SFP indicated that raising of eucalyptus on forest lands was one of the reasons why farmers did not feel attracted to grow commercial trees on their plots.

Suggestions for subsistence regions

The factors disclosed above have limited the spread of market-oriented farm forestry to the subsistence regions. A different approach is required, which would be in harmony with the ecological characteristics of these regions. First, a great deal of research needs to be done to identify species which complement agricultural production, as farmers' primary land use continues to be crop production. Thus, the objective should change from 'how can farmers be persuaded to grow trees?' to 'in what manner can technology help in increasing overall production from marginal lands by meeting farmers' priorities?' Ultimately the programme must improve the productivity of degraded private lands, if it is to be sustained over a long period. There are some known indigenous practices, which use trees to improve land productivity. Similar practices have to be introduced extensively in these regions. For instance, one should give greater importance to species like *Siddha* in Orissa, which can easily provide a great deal of fuelwood to the poor families as it can be continuously harvested for fuelwood. It also does not require any decision about distribution between the rich and the poor. Such a tree is not of much interest to the rich, as it requires labour for gathering. Thus, by default, the benefits are available primarily for the poor. If such species require more time at the nursery stage, these could be raised in a central nursery, and then transported to the temporary nurseries. It is difficult to rehabilitate degraded lands without introducing moisture conservation and water-harvesting measures, which are essential for all the rain-fed areas to undertake biomass production. The soil conservation technology in India has so far focussed primarily on structural works for controlling and disposing of run-off rather than capturing the maximum amount of moisture in the soil and retaining it for as long as possible to support crop growth. It is better to adopt *in situ* moisture conservation practices through planting of suitable grasses and trees, which may also provide sufficient protection against erosion. Equally important are institutional constraints in watershed management programmes. Studies of other similar programmes show that planning, organization, and management have been issues of major concern in all projects. In particular, the impact of watershed treatments has been impaired by poor coordination between line agencies, and there has been a marked absence of land user participation in treatment planning and implementation.

Unfortunately, the watershed approach and agroforestry research for different agro-ecological regions has remained a neglected discipline so far. Due to a tradition of

competition for land between the Agriculture Department and the FD of the government, both have viewed agroforestry with suspicion. The FD has even gone to the extent of banning agroforestry on forest lands by law.

Problems of allottees

Under the FFRP scheme, landless farmers are allotted 0.5 ha revenue land (wasteland), and are given seedlings for plantation. If the farmer shows satisfactory progress (survival of trees) after three years, he is to be issued a usufructuary lease (tree patta). Even though the scheme has been in effect since 1985, no *pattas* have been issued as yet. The question of how to do it was referred to the central government, which concluded it to be wholly within the jurisdiction of the state government to issue the *pattas*. Since this decision, the matter has been with the Government of Orissa. The question of delays in issuing of usufructuary rights (*pattas*) to the beneficiaries of the FFRP component is a source of apprehension for most of the farmers involved. Because of the delays in issuing of *pattas*, allottees feel that their legal status is precarious. They believe they have no legal right to the planted trees until the written *patta* is issued, with the effect that no farmer has applied for timber transit permits as yet. Several farmers claimed to have had trees stolen from their plantations without being able to file any complaint with the police. They do not know how to convince the police that they – landless as they are – own trees.

Commercial regions

Some regions in Orissa, such as the coastal areas, are more suitable than others for market-oriented farm forestry. Here, the approach should be to link them with markets and industry. This would require a review of legal restrictions on harvesting and sale of trees.

In the case of wood from plantations under farm forestry and FFRP, the Timber Transit Rules apply. These were amended in 1991 and 1992 especially to facilitate trading in the wood produced under these components. Now a transit permit is no longer needed for the two main species grown in the project, eucalyptus and *Acacia auriculiformis*. But such restrictions continue for other species, such as bamboo and casuarina. The procedure for obtaining a transit permit is as follows: (i) before felling trees, the ownership of the land and the trees must be certified by a 'joint verification' by the RD and the FD; this entails officials from both the RDs and the FDs inspecting the produce *in situ*; and (ii) after the joint verification, the farmer submits a list of conversions of trees and bamboos felled to the District Forest Officer (DFO). The DFO verifies (by physically marking the wood with the FD hammer) that only what is mentioned in the list actually is to be transported.

Thus, the whole procedure requires three visits to the site by RD and FD officials and some communication between the farmer and the said departments. Understandably, a farmer finds it cumbersome to approach two different departments on at least three occasions, especially since communications between a remote village and centralized departments are bound to take time.

Due to the degree of complexity of the transit permit rules, not many farmers can be expected to fully comprehend them – a factor that might render the farmers easy targets for exploitation. A survey of 12 villages in Sambalpur district in 1991 showed that only 60% of

the farmers interviewed had any conception of what the transit rules signify. Of these, hardly 10% had sufficient knowledge to explain the procedures of obtaining a permit.

Lastly, the government should stop subsidies on government supply of wood to industries, thereby forcing the industry to buy from the farmers at a remunerative price. The entire programme of farm forestry will be frustrated if captive plantations and subsidies continue. The FD could also initiate schemes for linking farmers with industries, in ways similar to the linking of poplar-growing farmers with a Swedish match factory in north India. Farmers will mostly produce eucalyptus for the paper industry, of which lops and tops can be used as fuelwood.

Production for the market

Though market demand for forest products is likely to conflict with the goal of increasing supplies to subsistence users, it is essential to the success of farm forestry, and in particular of FFRP, which depends upon growers being able to sell at least part of their output. Fuelwood markets and marketing in Orissa are quite complex. A three-tiered price system exists – the heavily subsidized price applicable to rural people for their own use, the administered price paid and charged by the Orissa Forest Corporation, and the free market price. The situation is further complicated by a multiple supply system. headloaders, merchants, contractors, and the Corporation.

One effect of the subsidized prices is to create a very low cost source of supply of wood available for use as fuelwood, priced at well below the cost of replacement of growing stock through investment in plantations. As long as this source is available, growers are unlikely to be able to sell their trees to middlemen as fuelwood at a price that would be commensurate with the costs they have incurred.

The low value of fuelwood also means that, in most situations, it is likely to be a less profitable crop for farmers than the growing of trees for sale of poles, construction timber, fruit, etc. This needs to be reflected in the choice of species and management systems recommended to farm forestry and FFRP beneficiaries. It is likely that fuelwood production will be profitable only in a few special situations – for example, on the agriculturally marginal sandy soils of the coast close to markets; or when they can themselves sell directly to markets, thus benefiting from the much higher prices for the new product as compared with the price for the tree.

The relatively low market value of fuelwood also undoubtedly helps explain the preference villagers have been expressing for tree species which primarily yield some other product – timber, fruit, bamboo raw material for further processing, etc. These not only have a higher market value, but are also less easily substituted by other locally available raw materials. A shortage of wood for construction or of bamboo for local artisans is thus more sharply felt, and is likely to lead to higher costs for the villager rather than shortage of fuelwood.

The multiple species woodlots, stocked to produce such locally sought after materials, are therefore consistent with the forest products supply–demand situation prevailing at the village level. But it does mean that what is being created is a resource with a considerable market value. This, once again, raises the question of how well this will serve the needs of the poor for subsistence requirements.

A village-level study indicates that farmers possess a limited knowledge of prevailing market prices and of the produce in demand. Only 45% of the farmers had any idea of where to market their produce (only seven per cent had a good idea), while 55% of all farmers had no idea of what price to expect. Most of the price expectations tended to be above the prevailing market price. The implication of this low level of knowledge is that markets would not be able to function efficiently since one of the basic prerequisites of market efficiency – full, or, at least, sufficient information among the actors – is not fulfilled. In practice, it will mean that farmers risk exploitation by buyers. Lack of knowledge immediately places the farmer in an inferior position to a buyer who has knowledge of prices prevailing, and what type of produce is in demand.

A further legal impediment to commercial activity under the project is the legislation relating to the sale of trees by members of the scheduled tribes and scheduled castes. Such sale requires a special permit. Although this legislation was introduced to protect those to whom it refers against exploitation (many tribals, for example, own trees having a timber value of which they might be unaware), it is obviously two-edged. Many of the project beneficiaries are subject to this legislation, which needs to be reviewed.

Fuelwood distribution from community woodlots

One of the main factors sustaining people's involvement in the SIDA project is their expectation of sharing its material benefits. In areas where intermediate produce from woodlots had been distributed, the following methods of distribution were observed.

- Twigs and branches were made into bundles of equal size and distributed on the basis of one bundle for one kitchen.
- Where economically better-off sections preferred not to take material, it was sold to whoever was willing to buy at a nominal price, and the proceeds were remitted to the fund. In such cases, the buyers were invariably the poor.
- Fallen dry leaves were allowed to be collected by interested people on a 'sweep and carry basis'.
- Where damage to standing trees was observed to be a consequence of too many people entering a plantation for sweeping, a contract to sweep was given to one or two persons only. The contractors were permitted to sell the leaves at Rs 0.25 per 5 kg to the villagers who protected the plantation, and at twice that price to members of other villages.

Each of these methods of sharing the forest produce has its merits, although one may have reservations regarding the last, which relies on contractors and requires that the poor, whose need for fuel is more acute, have to pay a price, however small. But the merits and demerits of the sharing system are less important than the fact that the villages are developing their own innovative ways of sharing forest produce equally.

Subsistence use of fuelwood within the village is also bound to be increasingly affected by the growing market for this product, and the monetary value this places on it. In prac-

tice, the village is not isolated from the market economy, so that villagers both communally and individually could find it more advantageous to sell their fuelwood production outside the village than to use it themselves. Some villagers already see their tree resources as being more valuable as a source of revenue to finance community projects and activities than as a source of materials for use within the village. This is hardly surprising, given the lack of alternative sources of community income.

Economic pressures are, therefore, likely to encourage the diversion of VF output away from local subsistence use to higher valued market outlets. The provisions in the VF rules designed to prevent sales outside the village may not be enforceable, nor are they in the interests of the village as a whole.

This assessment, if correct, clearly has very fundamental implications for some of the main objectives of the government projects; the question of how to provide for the fuel needs of the poor probably needs to be rethought. Though programmes to introduce improved stoves, biogas plants, and other sources of energy may make useful contributions for those who can afford them, most of those who presently depend on gathered supplies of biomass fuels will continue to have to do so. More attention might usefully be directed to increasing resources of fast-growing high-yielding woody shrubs. These can often be diffused at a much lesser cost than trees; they can be cropped more frequently to give a more even flow of fuelwood; and, as they do not have alternative uses, the material they produce is less likely to be diverted to market outlets.

Independent initiatives of villagers

As already mentioned, in addition to government-sponsored committees, a large number of indigenous committees have also sprung up in Orissa. Community-based forest protection is not new to Orissa. Communities claim to have taken up protection as early as 1950s. Guesstimates of the area under protection and the number of communities involved range from 187 000 acres and 1181 organizations to 1.5 mha and 6085 villages committees (FD records).

Reasons for forest protection by committees

Orissa's acute poverty provides a challenge, and can also be seen as a positive factor, as it forces almost the entire population in a village to be dependent on forest resources. This dependence helps in the evolution of a viable village institution. The Orissa upland settlements are more homogeneous in caste, with one tribe usually dominating both in land and number. A study comparing the success of collective action in the poor state of Orissa with Gujarat, a richer state, noted that, in Orissa, livelihood options are almost nil, whereas, in Gujarat, migration or agriculture has provided an option to the communities to cope with the problem of deforestation. Hence, in Gujarat, despite external intervention either by the FD or by non-governmental organizations (NGOs) to act as catalysts, the programme has only been moderately successful. In Orissa, most forest protection committees (FPCs) have come up on their own initiative and have survived with almost no incentive from government. Finally, remoteness from roads and markets further helps in retaining mutual

obligations, and discourages poaching by outsiders. In remote villages, fear of reprisals from village elders too deters frequent abuse of common resources.

Another reason behind the people's success is the lack of full control of the FD over PFs, which facilitates people's control over such lands. In Orissa, unlike other states of India, the ambiguous status of PFs provides a highly favourable environment for the evolution of the community management system. The ownership of the PFs lies with the RD, and management effectively with none. Only in case of a few demarcated PFs, working schemes have been prepared by the FD. Thus, large areas of PFs have been left unmanaged. As the forest started receding further from the villages, the local communities realized that open-access usage of the resources was no longer a realistic proposition and some kind of user group regulation is required to safeguard the interests of the community. This resulted in communities undertaking the protection and management of forests, starting with PFs. Later, at a few places, RFs were also taken up for protection by communities which did not have adequate PFs in their vicinity or under their control.

Thus, an important factor behind the success of community action has been the long-term association of these villages with 'their' forests and the heavy dependence on these, and the loose control of the FD over PFs.

In most of the cases, protection efforts have started only when communities faced acute shortage of small timber for construction of houses and for making agricultural implements. Although there had been considerable reduction in the availability of fuelwood over the years, this had hardly been an initiating factor. Small timber requirement, monetary benefits, and greater availability of non-timber forest products (NTFPs) such as *sal* seed has often initiated the process.

When one or a few villages in a cluster take up protection, accessibility to a particular patch by people from other adjoining villages is restricted. This often triggers off the protection movement in the nearby villages, whereby each village starts asserting its right over a patch of land. This restricts each other's access.

Leadership plays an important role in the introduction of the concept of protection to a community. In some cases, it was provided from outside the village (by FD personnel), whereas, in some, it was provided by influential people from within the village. Leadership was dependent on the population composition. The more homogeneous composition, the better was the leadership.

Rights of villagers over the protected patch play a critical role in the initiation of the protection effort. Where people have been assured that benefits would flow to the community, protection could be brought about. However, most of the villages in a cluster took up protection only after they had seen the rights of other villagers over the protected patch being recognized by the FD, although informally. This reflects the importance of clarity in the rights of the villagers over the protected patch.

Institutional arrangement evolved

Several kinds of organizations have been formed at the village level to take up the management of forests: youth clubs (YCs), village councils (VCs), village forest protection com-

mittees (VFPCs), etc. VFPCs are generally of two types: one that is formally set up by the FD under the guidelines issued for the purpose, and the second type being a sub-committee of the VC entrusted with the management aspect of the forest. In some villages, although a formal VFPC had been formed by the FD, management was being looked after by the YC. Very few people were aware of the composition of the formal committee or the area they were protecting.

Budhikhamari, where more than 55 villages were jointly carrying out protection and which has received several awards, was unique in this aspect. The VCs of the individual villages were looking after protection and each VC was represented by a president and secretary in the central committee called the joint protection party (JPP). Each organization, irrespective of its kind, had a president and a secretary generally elected by consensus. Care was taken to involve people from all sections in case the village had a heterogeneous population. Each community had a general body with one person from each household, and a core group comprising four to five persons responsible for taking decisions on day-to-day activities. Most of the committees were found to be struggling under financial constraints. In order to meet expenses incurred in the protection, collection was made in cash or in kind. Expenses were also incurred in conducting rallies for bringing about environmental awareness, conducting meetings, payment to watchmen, etc. Revenues for this were chiefly from cleaning and thinning materials, which were sold to the villagers at a subsidized rate. Other sources of revenue included the fines collected for the violation of rules by the people within or outside the village. However, it was found to be insufficient to meet the expenses incurred in protection. Funds collected by the VC from other sources, such as from the village pond, had to be diverted to the forest management. This often proved to be a disincentive to the villagers, particularly the weaker sections who perceive protection as an additional economic burden. It was reported that the YCs were highly effective in the protection aspect because of their tough stand against offenders, and this had often been the reason why the VC had handed over the protection responsibility to the YC.

Fuelwood pressure shift

A shift in fuelwood pressure in each cluster was very evident. Each village in a cluster had its own method of meeting its domestic energy needs. The first source of fuelwood was within the village boundaries. Some villages had demarcated certain areas, which included a part of the VF and pasture land, for the collection purpose. In some villages, while protection was being done in one patch, indiscriminate fuelwood collection was being carried out from another part of the VF and pasture land. While vegetation flourished in one part, degradation continued in adjacent patches. Often the VF was seen as the property of the village, whereas the RF that of the Department. So, while the protection of degraded VFs was taken up, the well-stocked RFs were left as open access. As a result, these forests have now reduced to open scrub vegetation.

This raises the question as to what would happen with respect to fuelwood availability if the total area around a village is protected? In such cases, the fuelwood pressure shifts to

two other places: first, to those distant RFs with good growing stock, which are managed without community protection. Cycle-loads of fuelwood are illegally extracted everyday from such RFs by people from those villages with no area under its protection or, if present, was very small and highly degraded. Conflict often emerged between the cycle-loaders and the people of the village through which they generally passed. Cycle-load trading became a lucrative business, as demand for fuelwood increased and supply curtailed due to protection efforts in the cluster.

The second type of pressure shift has been to those PFs and RFs where the village committees were found to be less effective in their protection activities, often due to internal conflicts, financial constraints, and lack of leadership.

The problem of fuelwood pressure shift was relatively less in Budhikhamari, where more than 55 villages were jointly carrying out protection under an umbrella organization of JPP. Energy requirements were met partly from collected dried fallen twigs, and collection of dried leaves has become a part of daily activity of tribal women in various clusters.

A few trends need to be analysed here. Why does a community protect a patch totally degraded with a view to get a significant benefit after two or three decades and not protect a well-stocked patch which would provide them benefits within a short span of time? It was generally felt by the villagers that it would be easier for them to assert their effort and not in the case of an already existing dense forest. Would this lead to a cyclic process of a degraded forest developing into a well-stocked forest and a well-stocked forest getting again converted to a degraded one? Further, well-stocked RFs or PFs are generally not taken up for protection because of fear of threats from within and outside the village boundaries. Threats emerge from those benefiting from a patch in terms of fuelwood and small timber when they are denied accessibility. Thus, degraded forests are brought under protection while well-stocked ones are left as open access property.

The issue of fuelwood pressure shift puts serious doubts on the effectiveness of this kind of protection. Can this pressure be contained in any way? Can the cluster approach, where all the villagers are involved in the protection, provide an answer to this kind of problem?

Although the cluster approach of protection does overcome the problem of pressure shift, certain issues in this regard need to be examined. First is the kind of leadership required to organize such a large number of villagers under a common umbrella. If inter-village conflict exists, then bringing all of them together may result in an abortive attempt to organize protection movement at a macro level. Second, when a number of villagers join together, they often perceive their mass as their strength and sometimes they misutilize the power. So, before organizing such a cluster, what control measures would the FD have to check such misutilization of power? And what should be the ideal size of the joint committee for effective administration?

Equity issues

Looking at the equity aspects of forest protection from the broader perspective, there are large-scale processes causing inequalities between villages. Some villagers have to share a large forest area with many other villagers, some have much smaller areas which they have

to themselves, and some are not adjacent to forest areas at all. Different rates of forest degradation and different degrees of awareness and concern have prompted some villages to take action and to exercise protective control over some forests much earlier than other villages.

Some smaller villages are concerned about being disadvantaged by the larger villages with whom they share access to a forest area. Members of a tribal village adjacent to Damasahi were critical of the people from the Damasahi village as they had taken over land that had been planted with trees given to the village by the government. When asked what sort of problems they expected in the future they said that as the forest gets thicker more people would be attracted, which could result in conflict, emphasizing that they are 'a very small village' and would find it difficult to oppose outsiders.

Potentially, forest protection can lead to a win-win situation, in that NTFPs can provide significant benefits to the poorest villagers; but the conditions for such benefits to accrue consistently will not exist until there is a general acceptance of rule systems which allow for access to these benefits by the poorest.

It may be that because in many villages it is the 'richer' households that are least dependent on the forest. Because of their relative status and authority, even NGOs that initiate community protection have pragmatically sought their active involvement in forest protection. To have such people on their committee was useful for dealing with other villages and external authorities.

Many village forest protection initiatives arise spontaneously when the forests have become very seriously degraded, to the point where even the poorest are having great difficulty getting any of their needs met from forest resources (for example, when rootstock are being dug up for firewood) At these times it is likely that everyone in the village, even the poorest themselves, see forest protection as a win-win situation, where everyone can gain, and few, if any, will lose

Nevertheless, there are circumstances where the needs of the poor will be at risk. Firstly, in forest areas where poorer households already have a stake in a forest which is still giving them some return, and in forest areas, especially plantations, where the distribution of returns from future cropping are yet to be agreed upon.

One problem area in particular is those households which are wholly or partially dependent on the collection and sale of firewood for income. Such people cannot stop cutting wood in forest areas even after the introduction of forest protection in their area. Sometimes wood-cutting has been displaced to more distant 'unprotected' forests. Often wood-cutting has persisted in the same village, albeit under continuing pressure to stop it from the other members protecting the concerned forest. In both cases, wood-cutting families are paying the costs of protection, in increased walking distances, or in harassment and fines. The basic issue is of the alternative livelihoods available to those dependent on the forest, and that does not seem to have been addressed as a development issue by the FD.

In one village, the idea of establishing a firewood plantation to meet the needs of wood cutters was rejected on the grounds that the best firewood trees concerned cannot be grown in plantation. It also seemed that the allocation of any special usage rights to forest areas to particular groups would inherently be a problem, because it would open up the

possibility of other groups making special private claims on common land. In another village, a group of 35 to 40 potters, who use wood to fire their pots, are directly dependent on the forest. It would be ideal if an area of land should be left for the use of potters, but this advice was rejected by the community, in favour of a policy of total protection. According to potters in the village, they need about three quintals of wood every month to fire 300 pots. Now they are having to purchase wood from the Corporation depot, and collect brushwood from a forest 10 km away. At the same time they do not get sufficient wood to maintain their past production levels. In such cases, VF protection is not a win-win situation.

The equity issues concerned with the current management of the forests pale into insignificance when compared to the impending problems of the future. The forests and plantations are maturing assets, increasing in value and visibility every day. None of the villages contacted had established any long-term management plans, especially for the allocation of benefits from plantations. It could be argued that this is in fact an unreasonable expectation at present, where sustaining what exists is the main task at hand. However, some current decisions, such as the planting of trees over a whole area, versus part-by-part, year-by-year, have implications for the ability of the villages concerned to take continuing yield from the land in the future. This, in turn, will affect the management of claims for benefits, with one-off distributions being more problematic.

Arrangements for guarding PFs vary between villages; some use voluntary labour on a rotating basis, others collectively pay for a watchman. It could be argued that the volunteer-based system is more equitable, because for the poorest households, cash is in greater scarcity than labour time. The optimal arrangement would seem to be the situation found in some villages, where volunteer labour is used by most (called the *thengapally* system) but the richer households, in practice, paid poorer people to do their shifts.

Gender issues

When women were asked about their preferences for different tree species for plantation, a marked difference was found between the 'better-off' castes and the poorer *Harijan* (low caste) women. The better-off caste women expressed their preference for teak and *sal* trees, which can be used for furniture, whereas the poor Harijan women expressed their preference for fruit-bearing trees like mango, jackfruit, guava, and *ber*.

Despite the above differences, all groups of women in general appear to have understood the need for forest protection and have expressed a positive attitude towards forest protection activities. In a village, women (not low caste but not rich) said that the most important benefit next to fuelwood was the availability of privacy for ablutions. They said that when the hills and the foothills were barren, they used to have to walk very far away from the village to find privacy. It was very hard especially if they needed this privacy during the day in summer. However, now the regeneration of bushes has made their lives easier.

In contrast to the better-off women, the poorer low caste women always emphasized their need for fuelwood, which they think can be met from the PFs. This was for their own

consumption, and, in some cases, for selling The better-off women, who have purchasing power to buy fuelwood, did not see the need to protect forests in order to meet their fuelwood requirements.

In the overall analysis of the problem of environmental degradation, the protecting committees feel that both men and women are affected equally, and the benefits of forest regeneration are shared equally by men and women. One section is not affected in different ways from the other. On the basis of this understanding, the committees have never felt the need to consult women specifically in the planning and implementation of the project activities. In none of the successful VCs or YCs were women represented or consulted. These were exclusively male societies.

Problems with government

Rather than trying to locate barriers to community action in structural and sociological factors, or in inter- and intra-village problems, greater attention needs to be paid to governmental policy, which has often hampered such initiatives JFM has been promoted in most states by the FD. However, in Orissa, there are indigenous committees which have been protecting forests for a long time. The establishment of these committees had nothing to do with the efforts of the FD, although individual forest rangers have often been involved in giving guidance to such committees. Thus, today, there exists no JFM n Orissa. However, there is forest protection and management by village forest committees (VFCs) – with the FD as a passive bystander/supporter or not knowing about it at all. The initiatives taken by the state government have often resulted in confusion, as described below.

No consultation

The state government orders of 1988, 1990, and 1993 in Orissa have officially led to formation of nearly 23 000 VFCs. Some of these VFCs are functioning very well, but a large majority have problems, and many may exist only on paper Often, they have been created in a hurry without paying attention to details, such as adequate consultation with local villagers. In some cases, the area being traditionally protected by villages was allotted to some other village for protection. In some other cases, villages considerably away from a forest patch were allotted areas, while the ones in the proximity were ignored. Such events occurred due to the formation of VFCs on paper by the field staff at Range Headquarters. This is a good example of how well-intentioned policy decisions are liable to lead to unforeseen and undesirable results, if not implemented properly.

No authority under law

The resolutions do not have the strength of law. Therefore, the VFCs are extra-legal bodies. The state government resolutions recommend village-level committees as functional groups. However, these committees have no legal and statutory basis, and it may be difficult for them to manage resources on a long-term basis The VFCs have no power of their own to punish or challenge offenders. Their authority over the forest is very often questioned This can be avoided if the VFC has legal powers over the patch it protects.

Recognize informal committees

One of the first needs of indigenous committees is official recognition in writing, through a letter which the village people can keep. It would be useful if the names of all families involved in protection were mentioned in the letter. However, this is not provided for in the rules. On the other hand, the Orissa government has a track record of not honouring commitments, or at least honouring them only after great delay, as in giving *pattas* to FFRP beneficiaries, creating VFs, etc. These committees can also be given some financial help, so that they can buy torches and uniforms for the watchman.

Ideally speaking, at some stage, the informal forest protection committees need to be formalized to give them legal endorsement. The transition/transformation from informal to formal organizations should be made as smooth as possible, with efforts to retain the strengths, namely, flexibility, representativeness, and acceptability by the community, of the informal organizations. The composition of new committees should be such that it incorporates these strengths. For this, necessary changes would need to be made in the existing government order The process of formalization of informal committees is very crucial and needs to be handled with utmost care.

RFs treated as open-access lands

In the RFs of Orissa, a forest patch does not have a well-defined and recognized user-group, admitting the rights of the entire population of that region or the entire forest area. This kind of a 'right-regime', which makes RFs open-access lands, is not conducive to successful protection, as rights of contiguous villages protecting forests may come in conflict with those of distant villages, not protecting but still having rights to enjoy usufruct. Therefore, at least in JFM areas, use rights should be reviewed in order to put them in harmony with the 'care and share' philosophy, which is the basis of JFM. This would require redefining the village boundaries so as to include the RF lands where JFM is to be promoted. Inclusion of RFs within the village boundary will strengthen the claim of the protecting village *vis-à-vis* others.

Demarcation

Demarcation and allocation of forest areas to the village communities for protection is a prerequisite to the proper functioning of the VFCs. This aspect has not received adequate attention in the 1993 guidelines. The result is that, in some cases it has not been done while in some others it has not been adequately conveyed to the villagers.

Demarcation and allocation should normally take the following into account: the prevailing rights and concessions in the forest area, i.e., who uses it for what purpose, is it informal and seasonal as, for example, for fuelwood, minor forest produce collection, headloading and grazing, and so on, and whether the forest area is already being protected by some village or a group of people. Neglecting these points will lead to either conflicts or irresponsible behaviour. This is one of the reasons for the oft-repeated complaint against VCs that they protect their forest area at the expense of the adjoining RFs. The counter-point is that if they do not have the right to manage the RF and practice exclusion, how can they be expected to protect it?

Uncertainty about sharing of produce

In the villages which have started protecting forests after the formation of VFCs or where the informal forest protection has been formalized, there is a sense of uncertainty over sharing of forest produce, both from the intermediate and final harvests. This uncertainty arises from the extra-legal character of the VFCs, mutual distrust between the FD and the villagers, lack of knowledge about the legal provision, and the general casualness with which the VFCs have been formed.

The present formula of giving a share out of the net income should be replaced by a share of gross income, which the people can easily understand. The village communities should have the freedom to decide whether this will be individually distributed or deposited in the fund.

Rights of the VFC

The rights and responsibilities of village communities and the FD have been specified in such a manner that the VFCs have been given most responsibilities and the FD most authority. VFCs' rights over the forest patch are not mentioned specifically, only certain concessions for fulfilling bonafide requirements are spelt out.

The VFC should have the powers of a court so that it can arrest and impose fines up to Rs 1000 which, if not paid by the offender, should be recovered as arrears of land revenue. The VFC should also have powers to compound an offence without any upper limit.

The rules should lay down general principles for expenditure on approved items. The VFC, in consultation with the DFO, should be authorized to decide the financial norms. Subject to these, the VFCs should be free to spend up to 50% of their annual income without obtaining sanction from the above authority. For the rest, they should send proposals to the Forest Officer (FO) concerned

The VFC should have full powers to distribute and sell fallen fuelwood and grass to the villagers. As regards sale of standing trees, the number of such surplus annual forest produce should be determined once in a year by the open meeting of the General Body of the VFC. The FD may send its representative to such meetings and advise the VFC on technical matters. The VFC should be free to conduct the auction of fallen trees in the presence of the entire village up to a value of Rs 10 000 in a year The tapping of NTFPs, by outside contractors or their agents, should be banned. Short training courses can be organized to equip the local people with the necessary processing technique. It should be the duty of the FD to prepare a working plan and get it approved by the VFC. If the FD does not prepare an approved working plan, the VFC will be free to prepare its own plan in the interest of conservation and development of forest.

Innovative silviculture

In keeping with the new policy, species choice and silvicultural practices will need a change in favour of usufruct-based trees and multiple outputs. Where a large number of people have claims to forest produce, low management and low value output (but high in biomass) solutions have, perhaps, a better chance of success. However, business seems to be as usual in the field, and commercial trees are continued to be encouraged and planted

on forest lands. For instance, the FD's present management of *sal* seems to be for timber, and, hence, only one shoot is allowed to grow. Since *sal* is an excellent coppicer, degraded forests and hills close to a village should be managed to maximize biomass, with many shoots, which can be pruned occasionally to produce fuelwood, besides giving *sal* leaves.

Many of the forest ecosystems of India possess a high proportion of coppicing species, while water and soil conditions also permit rapid regeneration and increases in biomass. Recent studies are also beginning to indicate that regeneration is linked to increasing biodiversity. Natural regeneration through voluntary community protection costs between 5–10% of the amount needed to establish monocultural plantations on the same land area. Studies in West Bengal and Karnataka indicate regenerating natural forests, after 5 to 14 years of protection, yielded growth rates between 3.4 and 8.8 tonnes of woody biomass annually, compared with 1.5–3 tonnes for plantations. At the same time, the costs for plantation established averaged Rs 10 000/ha compared to a maximum of Rs 600 for natural regeneration.

The NTFPs flowing from naturally regenerating forests usually yield more income and employment to community members, especially women, when contrasted with monoculture plantations. Under natural regeneration, many of the forest ecosystems studied also began yielding NTFPs much faster than degraded lands placed under monoculture tree plantations. Many grasses and leaves are available after three to six months of protection. Regenerating natural forests are also being associated with improved hydrological functions by slowing run-off and improving soil moisture and groundwater levels.

Conclusions

One problem with the over-promotion of JFM is that it can lead to massive donor interest and funding support, which may exceed the capacity of the forestry bureaucracy to absorb it JFM may indeed have been promoted beyond the capacity to implement it. JFM is process-oriented and does not lend itself to becoming a target-oriented programme Apart from the lack of institutional capacity, the technical skills to develop different silvicultural systems (to fulfil the varied objectives of management) also are insufficient. For instance, research on the economic and ecological impact of protection shows that although the people's main concern is with fodder, protection beyond six years tends to close the tree canopy and reduce grass production Perhaps a much wider spacing is called for to maintain grass production, which is one of the major incentives for community protection and management Similarly, most silvicultural research in India so far has been done on commercial species, and techniques for large-scale regeneration of multi-purpose species, such as mahua and neem, are yet to be developed.

A development concept faces very different constraints and opportunities when it is new, unproven, and not accepted, compared with when it is long-established and widely accepted – and the role of those who are in charge of its promotion must vary accordingly. For example, much of the effort of the sympathizers of JFM to date has concentrated on promoting the principles of JFM to the government, NGOs, and local communities. Such promotion may be valuable in the early phases of a programme, but there are potential

problems in sustaining it for too long. The nature of promotion results in too much emphasis on positive aspects of the programme and too little critical analysis At the outset it is important to be able to persuade key actors of the merits of JFM, but it eventually becomes important to temper this with critical appraisal, long-term strategies, and the building of capacity to implement such policies. Care will need to be taken to ensure that JFM does not just become another development bandwagon.

Reference

ORG. 1991. *Wood Balance Study – Orissa* Bhubaneswar· Operations Research Group.

FRAMEWORK FOR BIOMASS ENERGY TECHNOLOGY PROMOTION IN MOUNTAIN AREAS

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Background

The economics of the Hindukush Himalayan (HKH) region[1] is characterized by low levels of development reflected in poverty and heavy dependence on biomass energy. The levels of income and development differ within the HKH region as the strategy adopted for the economic growth in each country is different. The levels of natural resource endowment and the patterns of energy consumption and energy resource mix also vary greatly This variance notwithstanding, the region exhibits growing environmental stress Natural resources, specifically forest and water, are threatened by the food and energy needs of the growing population represented by subsistence economic conditions evident in the increasing rate of deforestation (ADB/ICIMOD 1992).

The countries of the HKH region have a total population of 2365 million, of which more than five per cent live in the mountains. The average population density in the region is 154 persons per square kilometre, while it is 36 within the HKH region. There is substantial variation in population density across the countries, from 130 in Nepal to 12 in China. Table 1 summarizes selected development indicators in the countries of the region.

The infant mortality rate varies between 31 and 129 for 1000 births in the region. There are significant variations within the region with China and Myanmar having a higher Human Development Index (HDI) whereas low level of literacy and a high percentage of

[1] The 3500 km of mountain range that stretches from Afghanistan in the west through Pakistan, India, China Nepal, Bhutan, Bangladesh to Myanmar in the east is home to more than 120 million people

TABLE 1

Development indicators of the countries of the HKH region (1992)

Descriptions	Population (in millions)	Area ('000 Km²)	People in absolute poverty (%)	Adult literacy (%)	Infant mortality (per 1000 births)	GNP per capita US $	HDI	Industriali-zation ratio (%)	Urbaniza-tion ratio (%)	Population without health (%)	Access to water (%)
Afghanistan	21.5	652.2	47	29	—	—	0 21	—	—	46	71
(HKH only)	14.5	390 5	—	—	—	—	—	—	—	—	—
Bhutan	1 5	46.5	—	38	129	180	0 15	36	6	33	73
(HKH only)	1 5	46 5	—	—	—	—	—	—	—	—	—
Bangladesh	114 4	144 0	81	35	91	220	0 31	26	18	42	—
(HKH only)	1 2	13.2	—	—	—	—	—	—	—	—	—
China	1162.2	9581 0	9	73	31	470	0 65	34	27	10	18
(HKH only)	19.9	1647.7	—	—	—	—	—	—	—	—	—
India	883 6	3287 3	40	48	79	310	0 38	44	26	—	—
(HKH only)	37 3	482 9	—	—	—	—	—	—	—	—	—
Myanmar	43 7	677 0	35	81	72	230	0 41	17	25	52	69
(HKH only)	5 9	280 9	—	—	—	—	—	—	—	—	—
Nepal	19 1	147 2	65	26	99	170	0 29	26	12	—	62
(HKH only)	19.1	147.2	—	—	—	—	—	—	—	—	—
Pakistan	119 3	796 0	29	35	95	420	0 39	45	33	11	55
(HKH only)	23 2	404.2	—	—	—	—	—	—	—	—	—
Regional average	—	—	26	59	56	384	0 51	37	26	9	14
Regional total	2365.3	15331.2	—	—	—	—	—	—	—	—	—
HKH average	—	—	—	—	—	—	—	—	—	—	—
HKH total	122.6	3413.0	—	—	—	—	—	—	—	—	—

Sources. CSO (1985a; 1985b); PCB (1985; 1987); SSB (1985); Hill (1988): UNIDATA (1991); BBS (1993). FBSP (1993), NPC (1993).

poverty are reflective of the poor quality of life for a major part of the population. There are also variations within the countries and within the HKH area.[2]

A large majority of the population remains without access to safe water and adequate health facilities: poverty levels are high and as per the UNDP report on Human Development (1994), out of the total poor of 1175 million in the world, the region has 625 million and most of these fall within the HKH region. Though economic growth and development has improved living conditions, the HKH area remains one of poorest in the world. Figures 1–4 present the various development indicators.

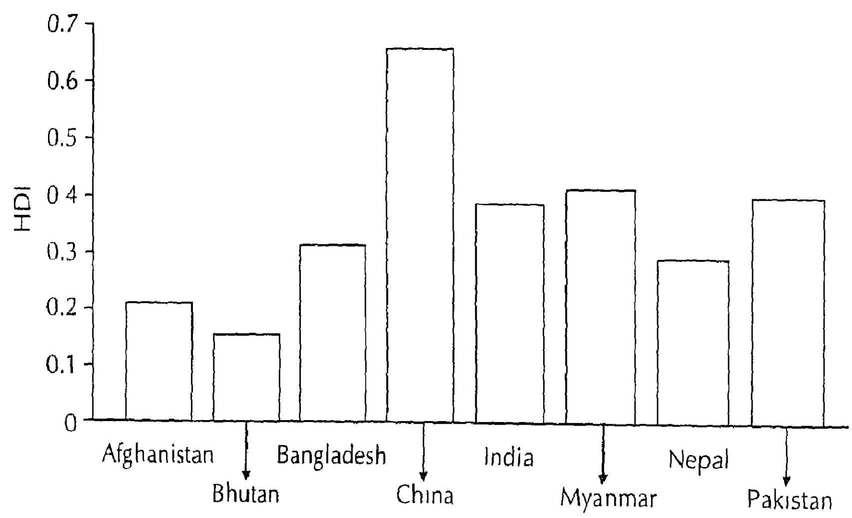


Figure 1. HDI in the countries of the region

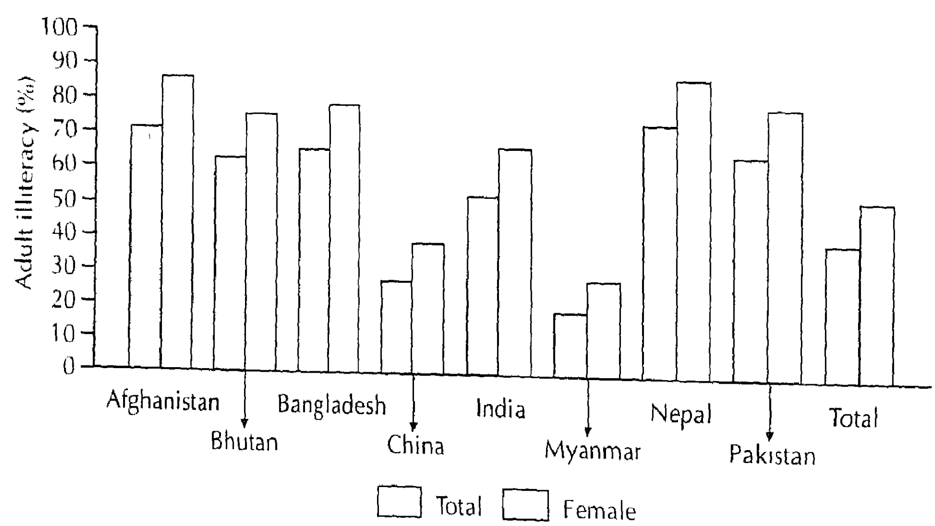


Figure 2 Percentage of adult illiteracy in the countries of the HKH region

[2] For example, one of the districts of Nepal – Kathmandu – has an HDI of 0 4

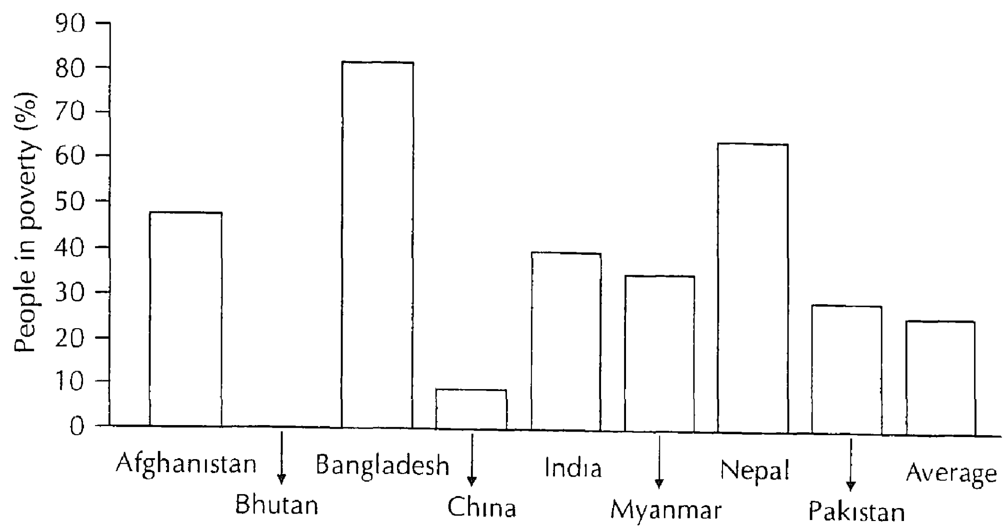


Figure 3. People in absolute poverty in the countries of the HKH region

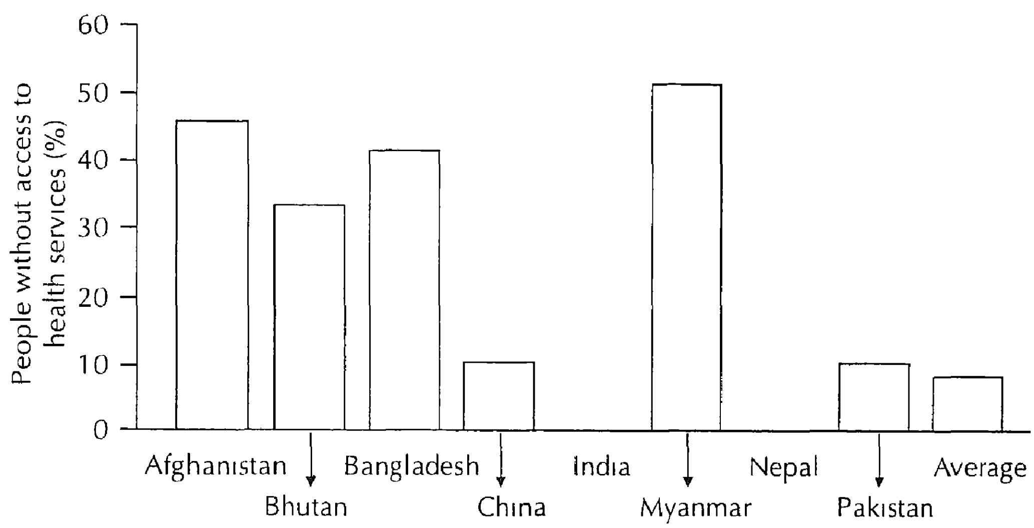


Figure 4. People without access to health services in the countries of the HKH region

Current energy situation in the region

Energy consumption and supply

The total final energy consumption amounted to 71 311 million GJ in the region in 1992, out of which 66% was met by commercial sources, and the rest by traditional fuels, though large variations in the share of traditional fuels are observed For example, in countries like Afghanistan, Bhutan, Nepal, and Myanmar, the share of traditional fuels lies between 75 and 95%, while in countries like China and Pakistan it is less than 25% as shown in Table 2. Big countries like China and India consumed about 66% and 29% of the total energy, respectively, while the remaining countries consumed less than 5%.

TABLE 2

Energy consumption pattern in the countries of the HKH region (1992)

Energy forms	Units	Afghanistan	Bhutan	Bangladesh	China	India	Myanmar	Nepal	Pakistan	Total
Hard coal	'000 tonnes	8	18	338	1090809	240405	34	92	4222	1335926
Coke	'000 tonnes	0	0	0	78999	10800	10	0	737	90546
Lignite	'000 tonnes	0	0	0	0	16560	39	0	0	16599
Fuelwood	'000 m³	19852	1843	7900	611295	549347	22358	15569	17065	1245229
Agricultural and animal residues	'000 tonnes	1985	90	29033	339820	376303	360	2425	10784	760800
Liquefied petroleum gas	'000 tonnes	0	4	8	3508	2760	4	6	151	6441
Motor gasolene	'000 tonnes	82	3	106	25753	3762	121	19	1131	30977
Kerosene	'000 tonnes	10	5	424	4322	9597	11	97	607	15073
Jet fuel	'000 tonnes	83	0	24		1100	19	19	431	1676
Diesel	'000 tonnes	125	15	1042	35290	24430	272	147	5026	66347
Fuel oil	'000 tonnes	2	0	444	34545	10050	115	10	3298	48464
Natural gas	TJ	7373	0	195306	614720	455760	37950	0	467310	1778419
Electricity	million kWh	834	185	9554	758920	329340	2674	926	51972	1154405
Thermal	million kWh	225	7	8758	621470	251285	1395	61	30965	914166
Hydro	million kWh	478	1620	796	132470	69848	1279	870	20582	227943
Nuclear	million kWh	—	—	—	—	6748	—	—	425	7173
Geothermal	million kWh	—	—	—	—	32	—	—	—	32
Import	million kWh	131	3	—	4980	1500	—	80	—	6694
Export	million kWh	—	1445	—	—	73	—	85	—	1603
Final energy consumption pattern ('000 GJ)										
Biomass fuels		257282	22711	458240	11433882	11168770	266129	212709	335536	24155269
Petroleum poducts		13606	1261	94502	4801950	2392089	25008	13719	489803	7831938
Natural gas		7373	0	195306	614720	455760	37950	0	467310	1778419
Coal		202	454	8518	29858357	6680286	1859	2318	128504	36680498
Electricity, renewables		2192	641	2866	494820	280998	4604	3114	75625	864860
Total		280655	25068	759431	47203729	20977902	335550	231860	1496779	71310974
Traditional energies		257282	22711	458240	11433882	11168770	266129	212709	335536	24155259
Commercial energies		23373	2355	301192	35769847	9809133	6942	19151	1161243	47155715
MJ per capita										
Biomass fuels		11945	15241	4006	9838	12640	6090	11160	2813	9204
Petroleum products		632	341	826	4132	2707	572	720	4106	1817

Contd...

Table 2
Contd...

Energy forms	Units	Afghanistan	Bhutan	Bangladesh	China	India	Myanmar	Nepal	Pakistan	Total
Natural gas		342	0	1707	529	516	868	0	3917	985
Coal		9	302	74	25691	7560	43	122	1077	4360
Electricity; renewables		102	528	25	426	318	105	163	634	275
Total		13031	16412	6638	40616	23741	7678	12165	12546	16641
Traditional energies		11945	15841	4006	9838	12640	6090	11160	2813	9204
Commercial energies		1085	571	2633	30778	11101	1589	1005	9734	7437
Percentage of total										
Biomass fuels		91.7	90 5	60 3	24 2	53.2	79.3	91 7	22.4	33.9
Petroleum products		4.8	60 0	12 4	10 2	11.4	7.5	5 9	32 7	11 0
Natural gas		2 6	0 0	25 7	1 3	2.2	11.3	0	31 2	2.5
Coal		0 1	0.5	1 1	63.3	31.8	0 6	1 0	8 6	51 4
Electricity, renewables		0 8	2 5	0 4	1.0	1.3	1 4	1.3	5 1	1.2
Total		100 0	100 0	100 0	100 0	100.0	100.0	100 0	100.0	100.0
Traditional energies		91 7	90 6	60.3	24 2	53.2	79.3	91.7	22 4	33 9
Commercial energies		8 3	9 4	39 7	75.8	46.8	20 7	8 3	77 6	66.1

Sources. UN (1994), ADB (1992)

There is also a wide variation in the per capita final energy consumption pattern within the countries. For example, in India and China, it is two to three times more than the average amounting to 16 500 MJ per capita, while it varies between 7500 and 16 500 MJ per capita in the other countries. This has been a consequence of various socio-economic factors besides the availability of energy resources and reliable technologies.

Given the unreliability of estimates of total energy consumption in the HKH region, the energy consumption pattern in the domestic section – as seen from various case studies – shows that the contribution of traditional fuels amounts to more than 90% of the total energy requirement except in Jammu and Kashmir (Tables 3a and 3b). The share of fuelwood in traditional energy exceeds 65% except in the Ningnan County of China. The trend indicates that the use of agriculture residue and animal dung as a source of energy is on the rise in the HKH region, but, in urban areas, the transition from biomass to commercial energy forms is at a slow pace. This can be safely attributed to the slow rate of growth of economic activities due to the prevailing development barriers.

The energy resource base of the region incorporates a combination of traditional and commercial sources including fuelwood, agriculture residue, animal wastes, hydro-electricity, and petroleum, coal, wind, and solar. The energy potential in the countries of this region is presented in Table 4. The present sustainable supply of energy amounts to more than six times the total energy consumption.

The resources available in the region vary significantly. For example, the share of coal occupies first place with more than 90% in China and India, whereas, renewable energy accounts for less than 2% in China and 6% in India, 8% in Bangladesh, and 11% in Pakistan In Afghanistan and Myanmar, sustainable supply of renewable energy amounts to 26% and 20%, respectively, while it is 100% in countries like Bhutan and Nepal. Though reliable estimates of the energy resource availability of the HKH are not available, the trend of resource availability as depicted in countries like Nepal prevails overall in the region. In Nepal and Bhutan, hydropower typically occupies the first place with more than 60% share, while biomass constitutes 4% in Bhutan and 10% in Nepal. The present usage pattern shows that biomass contributes more than 90% in meeting the current energy needs while hydropower contributes less than 1%.

Almost 94% of the sustainable supply is available in the form of coal – mostly in China and India. Only about 60% of the total final energy demand of the countries in the region can be met by sustainable supply of renewable energy assuming a loss of 50% during conversion of primary energy to final energy.

If India and China were to be excluded from the analysis, then the sustainable final energy supply potential would exceed 3.7 times, the total final energy demand assuming the overall conversion efficiency of 50% between primary and final energy supply.

It is interesting to note that if 70% of the present energy demand is assumed to be met by biomass fuels in countries other than India and China then only about 35% of this demand can be met by biomass fuels with the remaining having to be met by other means. This scenario is likely to present the prevailing energy supply pattern in the HKH region.

Energy use and human development

Scrutiny of the relationships between HDI, adult literacy, infant mortality and gross national product (GNP) per capita of the countries of the region shows strong correlation

Table 3a

Per capita final energy consumption in the domestic sector of the HKH region

Descriptions Natural unit per capita	Fuelwood (kg)	Agricultural Residue (kg)	Animal Dung (kg)	Biogas (MJ)	Kerosene (litres)	Electricity (kWh)	Coal (kg)	LPG (kg)
Nepal	450	164	105	0	8	12	0	0
Mountain	657	75	121	0	2	5	0	0
Hills	527	172	7	0	6	11	0	0
Terai	354	174	178	0	10	14	0	0
India								
Jammu & Kashmir	392	33	248	0	26	136	0	0
Himachal	874	198	59	0	8	106	0	0
Uttarakhand (UP)	577	87	0	0	6	19	0	0
Sikkim	447	52	0	0	12	7	0	0
North-eastern states	547	181	0	0	13	38	0	0
West Bengal	527	172	7	0	6	11	0	0
Bhutan	1848	0	0	0	6	9	0	0
China								
Ningnan country	358	402	0	44	3	16	15	0
Pakistan								
Swat district	719	20	12	0	6	62	0	19

Sources. Monga, Ramana (1992); Dhar, Sharma (1987); ICIMOD (1991a, 1991b; 1991c; 1991d; 1991e); WECS (1995); NPC/UNDP (1995).

Table 3b

Per capita final energy consumption in the domestic sector of the HKH region

Descriptions (MJ per capita)	Fuelwood	Agricultural residues	Animal dung	Biogas	Total biomass	Kerosene	Electricity	Coal	LPG	Total commercial	Total
Nepal	7522	2071	1140	0	10733	286	43	0	0	329	11062
	(68)	(19)	(10)	(0)	(97)	(3)	(0)	(0)	(0)	(3)	(110)
Mountain	10979	947	1317	0	13242	58	17	0	0	75	13317
	(82)	(7)	(10)	(0)	(99)	(0)	(0)	(0)	(0)	(1)	(100)
Hills	8803	2167	81	0	11050	217	38	0	0	255	11305
	(78)	(19)	(1)	(0)	(98)	(2)	(0)	(0)	(0)	(2)	(100)
Terai	5912	2191	1941	0	10044	380	52	0	0	432	10476
	(56)	(21)	(19)	(0)	(96)	(4)	(0)	(0)	(0)	(4)	(100)
India											
Jammu & Kashmir	6542	412	2703	0	9657	957	490	0	0	1446	11103
	(59)	(4)	(24)	(0)	(87)	(9)	(4)	(0)	(0)	(13)	(100)
Himachal	14591	2501	646	0	17737	288	382	0	0	670	18407
	(79)	(14)	(4)	(0)	(96)	(2)	(2)	(0)	(0)	(4)	(100)
Uttarakhand (UP)	9635	1096	0	0	10731	228	70	0	0	298	11029
	(87)	(10)	(0)	(0)	(97)	(2)	(1)	(0)	(0)	(3)	(100)
Sikkim	7457	651	0	0	8109	420	26	0	0	446	8555
	(87)	(8)	(0)	(0)	(95)	(5)	(0)	(0)	(0)	(5)	(100)
North-eastern states	9131	2282	0	0	11413	456	137	0	0	593	12006
	(76)	(19)	(0)	(0)	(95)	(4)	(1)	(0)	(0)	(5)	(100)
West Bengal	8803	2167	81	0	11050	217	38	0	0	255	11305
	(78)	(19)	(1)	(0)	(98)	(2)	(0)	(0)	(0)	(2)	(100)
Bhutan	30862	0	0	0	30862	227	33	0	0	259	31121
	(99)	(0)	(0)	(0)	(99)	(1)	(0)	(0)	(0)	(1)	(100)
China											
Ningnan county	5979	5071	0	0	11094	117	58	376	0	551	11645
	(51)	(44)	(0)	(0)	(95)	(1)	(1)	(3)	(0)	(5)	(100)
Pakistan											
Swat district	12001	254	131	0	12386	218	223	0	563	1004	13389
	(90)	(2)	(1)	(0)	(93)	(2)	(2)	(0)	(4)	(7)	(100)

Note Figures in parentheses indicate percentage values

Sources Monga, Ramana (1992); Dhar, Sharma (1987); ICIMOD (1991a, 1991b, 1991c, 1991d; 1991e); WECS (1995); NPC/UNDP (1995)

Table 4

Energy resource base in the countries of the HKH region

Energy forms	Unit	Afghanistan	Bhutan	Bangladesh	China	India	Myanmar	Nepal	Pakistan	Total
Coal	'000 tonnes	112000	—	1054000	286400000	131254000	5000	—	28590	418853590
Oil	'000 tonnes	—	—	4983	3264000	810000	7000	—	28826	4114809
Natural gas	mcm	100000	—	360000	1127000	730000	265000	5	728000	3310005
Uranium	MW	—	—	—	—	10000	—	—	10000	20000
Peat	'000 tonnes	—	—	138000	4687000	10571167	—	—	0	15396167
Hydro	MW	—	20000	1400	335000	150000	20000	83000	30000	639400
Wind	MW	—	—	—	—	20823	—	15	2642	23480
Biomass	'000 tonnes	15882	1382	34563	767726	760845	16011	13323	22729	1632460
Solar	MW	130400	9400	28800	1912200	657600	127953	26649	159200	3052202
Coal	million GJ	2822	0	26561	7217280	3307601	126	0	720	10555110
Oil	million GJ	0	0	229	150144	37260	322	0	1326	189281
Natural gas	million GJ	3600	0	12960	40572	26280	9540	0	26208	119160
Uranium	million GJ	0	0	0	0	158	0	0	158	315
Peat	million GJ	0	0	2484	84366	190281	0	0	0	277131
Hydro	million GJ	0	315	22	5282	2365	315	1309	473	10082
Wind	million GJ	0	0	0	0	328	0	0	42	370
Biomass	million GJ	233	20	506	11247	11146	235	195	333	23916
Average insolation	million GJ	2056	148	454	30152	10369	2018	420	2510	41827
Total	million GJ	8711	484	43217	7539043	3585788	12555	1925	31770	11223493
		(0)	(0)	(0)	(67)	(32)	(0)	(0)	(0)	(100)
Renewable	million GJ	2289	484	983	46681	24209	2567	1924	3358	82495
		(3)	(1)	(1)	(57)	(29)	(3)	(2)	(4)	(100)
Non-renewable	million GJ	6422	0	42234	7492362	3561579	9988	0	28412	11140998
		(0)	(0)	(0)	(67)	(32)	(0)	(0)	(0)	(100)
Yearly supply potential	MJ/capita	112232	322545	15972	169100	108013	63324	100964	32910	115633
Renewable		106269	322545	8589	40166	27398	58752	100964	28147	86604
Non renewable[a]		5964	0	7384	128934	80615	4571	0	4763	29029
Energy density	GJ/km²	3707	10294	12689	20555	29027	4088	13648	4932	12368
Renewable		3510	10294	6823	4882	7363	3792	13648	4219	6816
Non renewable[a]		197	0	5866	15673	21664	295	0	714	5551

Note Figures in parentheses indicate percentage values
[a]non-renewables being consumed within 50 years.
Sources. UN (1994); ADB (1992)

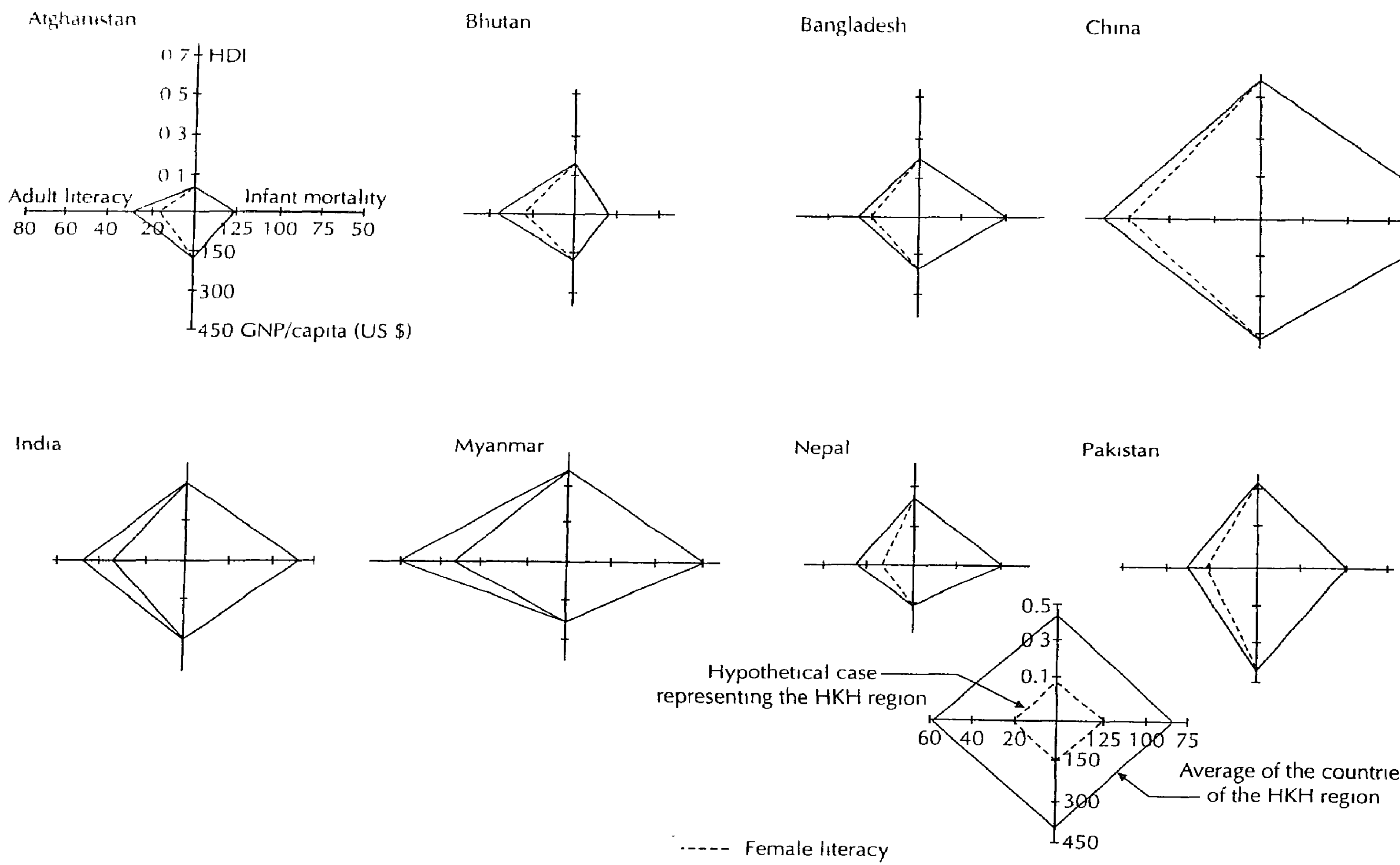


Figure 5. Human development indicators in the countries of the HKH region
Sources. World Bank (1991; 1992; 1993; 1994); UNDP (1991; 1992; 1993; 1994)

with some variations (Figure 5). These variations could be attributed to the policies and implementation strategies of respective governments and are indicative of how economic growth is tied with equity concerns and the governments' expenditure on social sector. At this point, it is interesting to note that on regional terms the average HDI, adult literacy, infant mortality, and GNP per capita are well balanced and the countries of the region seem to be doing quite well. Unfortunately, a closer look at the condition of the HKH region with HDI of about 0.1 indicates an increasing disparity among the people of the HKH region as against the rest of the population in the countries of the HKH region.

The relationship as represented in Figure 6 shows that the increased level of final energy consumption is a manifestation of the economic progress and better quality of life of the nation (Philips, Goldemberg, Johannson 1995). However, a close comparison between energy consumption per capita, HDI, industrialization ratio, and urbanization ratio among the countries of the region clearly reflects that the relationship depicted in Figure 6 does not completely hold true. This means that the level of energy consumption alone does not necessarily imply a desired level of human development, rather it means that there is a need to re-orient the energy development paradigm to one that suits the requirements and aspirations of the people of the HKH region.

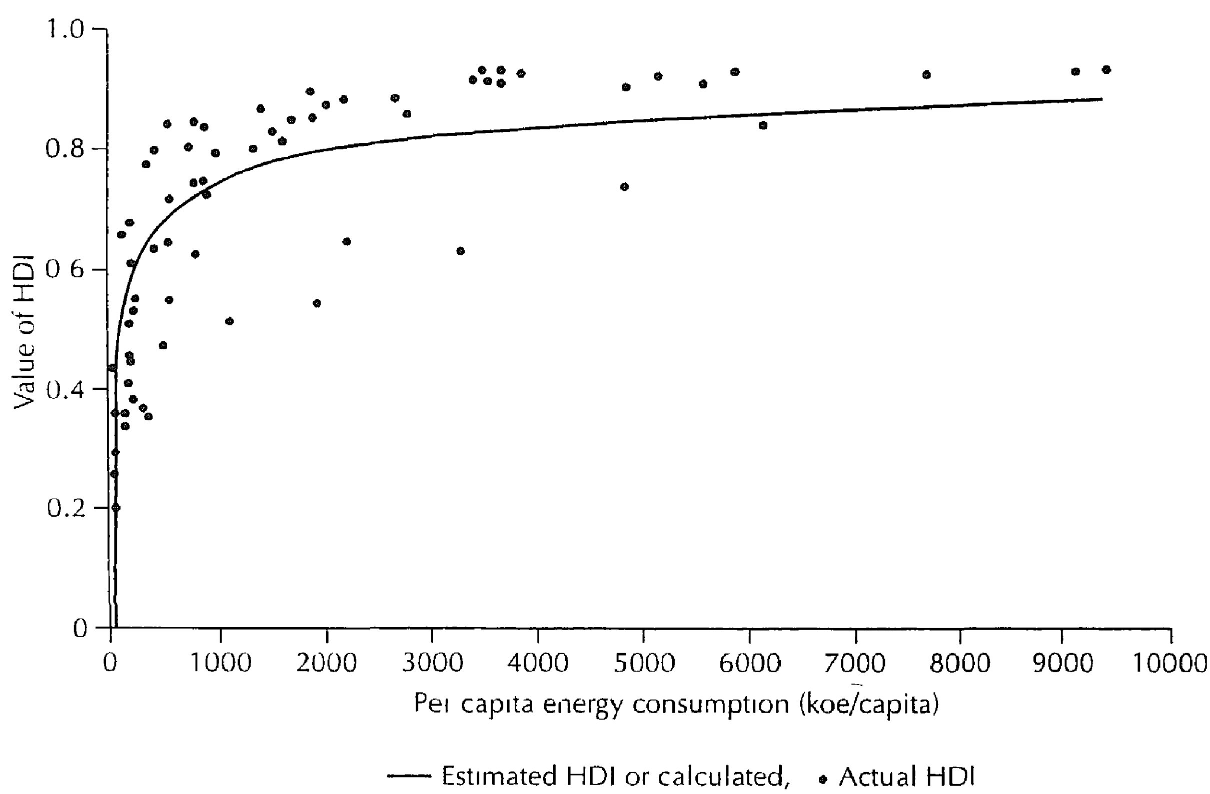


Figure 6. Estimated relationship between HDI and per capita energy consumption (1991–1992)
Note. Data for hundred developed and developing countries.
Source. Philips, Goldemberg, Johansson (1995)

Challenges in the development of the energy sector

Energy supply and demand imbalance

The HKH region is faced by a severe imbalance of sustainable energy supply and demand as discussed earlier. This is due to the fact that the development of renewable energy requires a large initial investment which, however, comes out to be cheaper in the long run. The economic cost of biomass fuels is rarely perceived by either the users or the nations and thus the traditional sources of energy still play a dominating role at the cost of the resource being degraded at the rate faster than it can be replenished.

The present trend of unsustainable and indiscriminate use of biomass resources has affected the welfare of the population in the HKH region as it raises the time spent in collecting fuelwood and fodder. It has likewise reduced the productivity of farms and adversely affected the quality of life (Monga, Lakhanpal 1988; Monga, Ramana 1992).

Lack of adequate, reliable, and affordable supply of energy in mountain areas, particularly for cooking, heating, and lighting, is a major constraint to the socio-economic development and improvement in the quality of rural life (Dhar, Sharma 1987).

Some of the common factors responsible for the poor performance of the energy sector in the HKH region are: centralized planning with a supply-oriented approach, lack of sufficient trained manpower, lack of standardization of equipment, distorted pricing structures, political pressure to sell commercial energy at less than cost-price, lack of R & D support for renewable energy development, etc. (Ramani, Reddy, Islam 1995; Munasinghe, Saunders 1989; Goldemberg *et al.* 1988).

Energy and environmental linkage: global concerns

The production and use of energy contributes negatively to the environment. It is widely believed that if the present trend of energy consumption continues, it will create environmental problems which in the long run could become a constraint for economic growth and social well-being.

The most prominent problem, recognized globally, is that of greenhouse gases (GHGs) CO_2, CH_4, NO_x, the main GHGs, are emitted mainly from the combustion of fossil fuels, deforestation, and biomass burning. Energy is estimated to account for more than 50% of the global GHGs (PEP Project 1995). The energy-related emissions in the HKH region are modest if estimated at the regional level, but are rising at an alarming rate in the urban areas of the region. Illustrating this phenomena are urban centres like Kathmandu and Dehra Dun which have already become some of the most polluted places in the region in terms of fossil-fuel-related emissions. The emission of GHGs caused by deforestation and biomass burning is bound to increase in the region in the event of economic transformation foreseen for poverty elimination and development of the mountain population as it would mean an increase in the demand for useful energy (i e heat, light, and shaft power).

Population growth has led to extreme pressures on the region's forest resources contributing to landslides, soil erosion and flooding, thereby endangering the lives of thousands of people every year. Furthermore, the possibility of substituting fuelwood by commercial fuels in mountain areas of the HKH region is limited mainly because of two reasons First, fuelwood collection is a subsistence type of non-monetized activity – it is

free if the labour cost is not considered. Second, the cost of distribution of commercial fuel is very high. Unless the cost of fuelwood rises considerably due to physical or economic scarcity this situation is not expected to change; the rural population, where per capita income is less than US $100, cannot afford to use modern fuels

The intricate relationship which exists between energy–economy–environment is understood generally. However, a lack of knowledge to capture the dynamic linkage among these sectors continues due to weak database and analytical capability.

Environmental health and poverty linkages

A particular concern is the health impact associated with the household use of traditional fuels. This issue has important linkages to the gender and generational aspects. The majority of the people, especially women and children are seriously affected by exposures of very high concentrations of emissions resulting from cooking with low-grade fuels and with stoves, and in poorly ventilated environments (deLucia 1993; Rijal 1994). The energy system transformation that reduces the health risks as well as poverty must be promoted.

Mountain specificities for and implications on the energy sector

Box 1 shows the numerous implications created by the mountain specifics (Sharma 1994; Jodha, Shrestha 1994, Banskota, Sharma 1994, Rijal 1996) on and for the energy sector.

Inaccesibility induces isolation which means high costs of energy supply system, which in turn, forces local residents to modify their needs to what they have.

Fragility reflects the vulnerability of energy resources. The decrease in productivity and low resource capability results in diverse settlements, and, consequently, the supply of energy infrastructure system which would mean high costs.

Marginality means that energy resources may be exploited by people living near the available resources and the rapid process of destruction becomes a visible phenomenon promoting extensive use of marginal areas by people without easy access to the resources. Furthermore, people residing in the mountains have a marginal say in the development process as the cost of not doing anything for the mountain people does not affect the power equation. Thus, it remains outside the major development negotiations, and, subsequently, energy technology interventions.

Diversity means that the cost of extraction of energy resources in usable form is high, and, because of the diverse nature the realization of economies of scale, is not feasible. In order to negate the economies of scale, particular resources and technologies tend to be used for multiple applications.

Given all these facts, the positive implication would be to capitalize on the diversity of the available energy resources for specific purposes by minimizing the constraints imposed by the mountain specificities. The positive outlook would be to capture the opportunities generated by the mountain-specific characteristics rather than harping on the constraints.

Box 1

Mountain specificities and implications on and for the biomass energy sector

Mountain specificities	Primary attributes	Adaptation characteristics	Implications on the energy sector	Implications for the energy sector
Inaccessibility	Isolation; high cost of supply system, limited access; invisibility of problems	Multiple use of resources and technologies	Interventions failed due to the sectoral approach	Better understanding of sectoral links, i.e., fuel, fodder, and food chain
Fragility	Resource highly vulnerable to rapid deforestation; low productivity and resources; disperse settlements	High community participation, people's oriented problem solving; integrated farming system; prevailing barter system	High costs of interventions; higher level of energy input	Augmented energy supply; improved efficiency of conversion
Marginality	Limited resources and productivity; minimal consideration of areas/people	Exploitation of potential by core areas/ population; use of marginal areas by others; dependency	Destruction at margin process	Encourage forest management to provide fodder, fuel, and timber
	Subsistence economy	Low risk-taking capability	Slow pace of dissemination	Link energy and income generation
Diversity	Diverse resource and approach environmental situation; large-scale micro-variations in physical/biological attributes; inter-dependence of production bases	Multiple cropping diversified up-land low-land farming systems	Increase in energy inputs, increased dependency on a specific fuel	Adopt need-based approach and diversify fuel use
Niche	Small-scale specialization; location and area-specific comparative advantage; location specificity of production and consumption	Emphasis on activities that are mostly of an extractive nature. logging, hydro-electricity	Decentralized energy system preferable	Indigenous technical knowledge-base for maintaining forest areas, traditional water wheels

Sources Sharma, Banskota (1992), Sharma (1994); Jodha, Shrestha (1994), PEP Project (1995); Rijal (1996)

Conceptual framework for the technology promotion: the case of biomass stoves

A basic feature of the HKH region is that the majority of the population which lives in the countryside is deprived of the amenities of modern cities and towns. These people are forced to lead simple lives, extracting virtually all their energy requirements from their environment. The price of this energy self-sufficiency, particularly for the poor and specifically the women and children, can be quite enormous in terms of human efforts. Thus, tedious and arduous labour is aggravated by the low efficiency of end-use devices. As a result:

- biomass is the principle fuel for cooking and space heating;
- animate energy is the main source of mechanical energy;
- the domestic sector is the main consumer of energy; and
- cooking and space heating are the dominant end-uses.

The objective of the energy system is to provide energy services. Energy services are the desired and useful products, processes, or services that result from the use of energy – for instance, illumination, cooking, and space conditioning. The energy chain that delivers these services begins with the collection and extraction of primary energy, which is then converted into energy carriers that are suitable for the end-uses.

It is noteworthy that it is useful energy which determines the extent of fulfilment of energy needs and improvement in the physical quality of life. Therefore, better efficiency of energy use permits significant improvements in the physical quality of life without increase, or even with decrease, in the amount of primary energy while at the same time it reduces the release of environmental effluent (Codoni, Park, Ramani 1985). Also, when a particular energy carrier is used efficiently or a shift is made into more efficient energy carriers, then inefficiently used sources will be available for alternative uses (Goldemberg *et al.* 1988). For example, large-scale dissemination of improved cookstoves may possibly allow animal dung to be used as farm-yard manure.

Misleading perception: problem of diagnosis

In the rural mountain areas, more than 90% of the total energy is for domestic activities, mainly for cooking, space heating, and lighting. On account of primary energy supply, cooking requires almost 70–80% of the total energy whereas space heating accounts for less than 25%. From the energy services point of view, however, useful energy required for space heating exceeds 60% while useful energy required for cooking amounts to 25–40% in mountain communities (Rijal 1991; PEP Project 1995; Islam, Morse, Soesastro 1984). Substantial variation on space heating requirement depends on the climatic condition of a specific location, the building envelope, the energy resources, and the technologies employed. The exact variations are not yet properly understood.

During the early 80s awareness of the wood-fuel crisis resulted in a proliferation of technologies. Improved cookstoves were conceived to reduce the fuelwood consumption level. These efforts were also initiated in the mountain areas of HKH. Almost all community

forestry as well as energy programmes initiated in the hills and mountain communities had major components of improved cookstoves claiming to save 25–35% of fuelwood consumption (CFDP 1984; Islam, Morse, Soesastro 1984; Pradhan, Rijal 1988).

The cue for crisis was dictated in the developed world, technological interventions conceived there without properly understanding the needs of the local community, and little room left for the developing nations to understand and modify programme components to suit their needs. In a hurry to improve the efficiency for cooking, a major end-use for mountain communities – space heating – was forgotten. Also, multiple use of resources and technologies was mostly neglected, this being a common phenomenon in the subsistence economy of mountains.

Fuelwood was believed to be needed primarily for cooking and its requirement in space heating was not given due consideration. Most of the technologists were only concerned with the pot utilization efficiency (PUE) for cooking and the suggested technological interventions considered PUE as a guiding principle.

The traditional supply-oriented approaches of meeting the energy needs of mountain population are the main causes of the improved cookstoves programme failures. But there are other reasons: (i) adequate consideration was not given to the religious, cultural, and ethnic background; (ii) target group identified for imparting information and training was faulty; (iii) efficient technology was distributed in areas where fuelwood was still easily available at no price; (iv) dissemination programmes were not carried out through the right kind of agencies and institutions; and (v) the 'felt-need' of the people was not taken into account (Rijal 1987; PEP 1995; Rijal 1991).

Matching energy needs, technologies and energy resources

The objective of the energy system is to provide energy services. Energy services are the desired and useful products, processes, or services that result from the use of energy – space heating and cooking. The energy chain that delivers these services begins with the collection or extraction of primary energy (forest), which is then converted into energy carriers that are suitable for end-uses. These energy carriers (primary energy – fuelwood; secondary energy – charcoal) are used in end-use devices (stoves used for space heating and cooking) to provide the desired energy services.

Choices are available with regard to energy resources and technologies which primarily depend on their availability and prices, and the life and efficiency of the technology device. However, the selection of a particular energy resource and technology is not only dictated by technical parameters but also by social and cultural acceptability of the technologies.

Matching energy needs with energy systems in itself is a complex process and should be viewed as an integral part of the matching process. In general, the following steps should be considered for matching energy needs with decentralized energy system (Ashworth, Neuendorffer 1982).

Step 1. Understanding the socio-economic and spatial dimension

The selection process must be based on the area's socio-economic circumstances and spatial dimensions. The social needs of the mountain communities desire that the fireplace/space-heating devices be located at the centre of the house as it facilities greater interaction

among the family members of the mountain communities. Similarly, mountain-specific conditions such as inaccessibility warrant the use of low-grade indigenous fuels (i.e., biomass) rather than the use of commercial fuels such as kerosene

Step 2. Identification of energy needs

The next step is to determine which needs are of primary importance to the mountain population and what particular activities require energy. Continuous consultation with the communities is essential to prevent the imposition of outside biases. Too often, energy planners autonomously decide what is needed for the people, i.e., cooking needs while overlooking the space heating. If the mountain communities do not play a significant role in selecting what needs must be met first, they are not likely to actively support the technology introduction processes, assist in any necessary modifications, or maintain the energy system.

Step 3. Screening of technological options

Once the energy needs are defined, the process of narrowing down the range of technological options should begin The preliminary screening of the energy systems is the first component of actual matching of needs and technologies. The important characteristics of each energy need are identified and compared with the characteristics of each available unit to determine how the system fits the energy need. The preliminary screening employs a set of criteria relating to energy needs. These are (i) type of energy output required; (ii) temperature of energy required; and (iii) spatial distribution required The first criterion selects those technologies that provide the energy form required to meet the need without energy transformation. The second criterion identifies energy systems that produce a sufficient level of thermal or kinetic energy to perform the task. The third criterion addresses the problem of providing energy where it is required. For example, if energy must be delivered to several sites, the technological options selected should be such that energy supplies can either be moved efficiently and easily or can be located at each site.

Step 4. Matching technologies with the needs and resource base

This step should provide the data on energy needs and energy systems that determine their compatibility in a particular location. Together with the mountain communities, energy technologists should evaluate the local resources. The energy resource base should be evaluated on the following criteria: (i) physical availability; (ii) variability; and (iii) constraints on use. The first criterion determines the size of the resource base and current demands upon the resource. The second criterion explains the changes in the resources on a daily, seasonal, and annual basis. The third criterion clarifies with regard to ownership of resources, cultural and/or economic restrictions on use, and conflicting use of the same resources.

An illustrative example of the matching process with regard to cooking and space heating requirements is shown in Box 2.

Box 2

An illustration of matching process: cooking and space-heating requirement

Key characterization criteria:

- temperature of output;
- time-of-day of output;
- socio-cultural criteria (with specific emphasis on gender); and
- environmental criteria.

Best matches with need:

- biomass;
- passive solar; and
- building orientation and insulation.

Other possible matches:

- micro-hydro (electric);
- kerosene; and
- diesel (electric)

Advantages of best-match technologies:

- no energy transformation required;
- biomass energy systems do not depend directly on climate variations; are easily stored and eliminate the need to store output energy; biomass combustion is the most acceptable and convenient technology; answer for shortages of fuelwood may be to introduce more efficient space heating technology or to accelerte biomass production through plantation;
- proper building orientation will increase heat flow inside the house; and
- insulation will reduce the heat losses from the building envelope.

Problems with other possible energy sources:

- electricity is a high-grade energy and is undesirable to be used in heat applications;
- high cost of transporting kerosene and diesel; and
- conversion inefficiencies.

Framework for technology diffusion

Technology in context: biomass stoves

Successful diffusion of stoves depends upon understanding how the mountain people are accustomed to organizing their productive activities and regulating their social relationships as these relate to mountain specificities (Brulez, Lindner 1984; Dhar 1994; Soussan, Shrestha, Uprety 1995). It is into this socio-cultural milieu that efficient space-heating technologies must be introduced. If they do not fit, they will not be diffused, regardless of their technological promise.

A majority of the mountain population meet most of their cooking and heating needs, outside the money economy. Many of the rural households still intend to maintain self-sufficiency within their own community if not within the household. However, money and markets are becoming more important, and cash is required to meet a growing number of needs, including that for energy technologies.

Many productive relationships among the mountain people are still structured by kinship and casteism. The introduction of stoves designed to utilize biomass energy more efficiently and that cost money must take mountain realities into account.

The issue of equity also becomes critical as the mountain people do not enjoy the type of access to energy resources and technologies as their counterparts in the plains. This issue is not important as long as biomass resources is available in abundance. But as the biomass starts diminishing, the need for adopting efficient technologies demands a higher level of cash expenditure on energy commodities. At the same time, production base is gradually decreasing with increase in the population and also physical limits imposed by mountain specificities. These factors need to be given due consideration while designing the framework for the diffusion of stove programmes

The socio-cultural aspects of diffusion of biomass stoves are of particular importance where the adopters of the technology lie mainly outside the cash economy. For them, adoption of biomass stoves is governed by a more complex mixture of factors.

Factors promoting technical and economic acceptability

Review of literature (Rijal 1995, NRC 1984; CFDP 1984; Clarke, Shrestha 1987) shows that several factors (elaborated below) appear to enhance technical and economic acceptability of biomass-based renewable energy innovations with respect to mountain communities and would equally apply to diffusion of biomass stoves.

Structural simplicity and scale

Simplicity facilitates the acquisition and maintenance of technologies. It also lessens the risk of dependence on external support for operation, repair and maintenance, and minimizes the need for extensive capital investment. For example, the Lorena stove, developed in highland Guatemala in the mid-1970s and widely diffused in both rural and urban Honduras, had this virtue (Clarke 1985).

Use of familiar materials

Employing familiar materials, wherever possible, enhances technological acceptability by lessening the requirement for learning. Use of local materials and craftmanship will also increase diffusion. For example, the mud-chimney stoves that are being popularized in Nepal are gaining some momentum as this stove is primarily local made.

Employment of familiar techniques

If the techniques for designing, manufacturing, and operating are familiar, the advantage is clear. Reliance on these methods minimizes the need for special training and for external supervision. For example, the recent introduction of back boilers with the chimney stoves are being readily adopted by the people of Ghandruk (Banskota, Sharma 1996).

Integration with existing technology

The economic advantages of an innovation that fits readily into an existing technological management system are evident. This integration minimizes the capital and/or labour costs of adopting traditional production patterns to meet the requirements of efficient biomass stoves. For example, introduction of efficient biomass stoves integrated with traditional methods of food preparation, fuel collection, and storage will enhance chances of acceptance. Where such integration is lacking, there is a risk that the stove will be modified by users for better technological 'fit' in ways that diminish its efficiency.

Factors that promote socio-cultural acceptability

The following conditions in general appear to increase chances for socio-cultural acceptability with regard to biomass stoves (Clarke, Shrestha 1987; Clarke 1985; Islam, Morse, Soesastra 1984; NRC 1984; Pradhan, Rijal 1988; Rijal 1987), though these variables will have to be accessed in the context of each local culture into which they have to be introduced.

Compatibility with the existing work organization

An understanding of the indigenous systems of work organization is important for the successful diffusion of efficient biomass stoves. For example, where firewood collection and food preparation are women's work and stove construction is categorized as a male prerogative, motivation to accept efficient biomass stoves may be lacking (Rijal, Manandhar, Kharel 1987).

Reasonable cost of technology

To foster diffusion, the system of distribution must allow for the disposition of the efficient biomass stoves at a cost that most people can meet. For example, more localized the manufacture and distribution of stoves, the more widespread their diffusion is likely to be, since they can be better adopted to meet local conditions.

Integration with social structure

Compatibility with the existing social structure – family organization, system of stratification based on caste, ethnicity, gender – is also a factor in winning acceptance and ensuring diffusion of biomass stoves. For example, the relationship of efficient biomass stove diffusion to the social structure is exemplified by the problem resulting from the traditionally subordinate social status of women as male decision makers give women's needs lower priority. Thus, technology diffusion should target the women community.

Accommodation of authority

Understanding the local political system – the organization for making and enforcing community-wide decisions, settling disputes, and regulating relations with neighbouring people – and how it relates to the biomass stove programme will enhance the chances of adoption. For, only when local decision-making processes are understood, and those with true authority are identified, can effective plans be made to ensure popular local participation and acceptance

Creating a conducive institutional and policy atmosphere

Institutional atmosphere

A decentralized approach to energy planning and its distribution is a viable alternative to centralized energy system Decentralized approach here means going beyond the district to the villages through users groups. Improved stove programmes can be successfully implemented in a variety of institutional settings. Many NGO-run programmes may be more flexible, committed, and closer to users. Sustainable institutional setting in the long run, however, should come through participatory institutions at the grassroots level (Banskota, Rijal 1996).

A decentralized-user group approach also appears necessary from the transmission cost point of view. For a wider mountain community in remote and inaccessible parts, it may take many more years before their villages can be linked to the national grid system. A centralized system from a cost-effectiveness point of view tends to rely on relatively large-scale energy production units, e g., hydro-electric production, which in poor countries are often at the mercy of external capital. This raises serious doubts on developing an effective and efficient energy planning framework. Greater reliance on user group based systems may prove to be more sustainable (Banskota, Rijal 1996).

Policy atmosphere

Energy policy must emphasize renewable sources which implies that in the case of mountain areas of HKH, two options are available, namely, firewood and electricity. The promotion of energy efficiency (both technical and allocative) should receive priority in designing energy policy. Distorted pricing regulation is always detrimental to the promotion of efficient energy use as it causes faulty, inefficient fuel uses and gives wrong investment signals to consumers. In conjunction with programmes to increase energy efficiency, programmes should be implemented to sustain the supply of traditional fuel through improved management of forest and plantation programmes which requires strong grassroots institutions. In other words, conservation interventions should strike a realistic balance between sustainable supply and demand management. This requires not only an integrated environment-cum-economic policy and programme, but also an effective institutional framework from the national to the grassroot levels (Banskota, Rijal 1996).

References

ADB 1992 *Energy Indicators of Developing Member Countries of ADB* Manila· Asian Development Bank.

ADB/ICIMOD. 1992. Nepal. economic policies for sustainable development Kathmandu: International Centre for Integrated Mountain Development.

Ashworth J H, Neuendorffer J W. 1982 Escaping the rural energy dilemma· a process for matching technologies to local needs and resources *World Development* 10(4): 305–318.

Banskota M, Sharma P (eds). 1994 Development of poor mountain areas. *Proceedings of an International Forum* Kathmandu: International Centre for Integrated Mountain Development.

Banskota K, Sharma B. 1996. Impact of alternative energy technology in reducing pressure on forest resources in Ghandruk. Kathmandu: Centre for Resources and Environmental Studies.

Banskota K, Rijal K. 1996. Promotion and diffusion of energy technology in mountain areas issues and options. Paper presented at the *Regional Workshop on Stoves Used for Space Heating and Cooking at Different Altitudes and/by Ethnic Groups*, 12–16 February 1996. Jointly organized by International Centre for Integrated Mountain Development and FAO-RWEDP, Pokhara, Nepal.

BBS. 1993. *Statistical Yearbook of Bangladesh – 1992*. Dhaka: Bangladesh Bureau of Statistics, Ministry of Planning

Brulez D, Lindner H. 1984. Energy demand and supply in the Dhading district of Nepal. conceptual steps of implementing renewable energy programs. pp. 30–41. Consultancy Report to the Dhading District Development Project, West Germany.

Codoni R, Park H, Ramani K V (eds). 1985. *Integrated Energy Planning: A Manual* (Vol. 1 to 4) Kuala Lumpur. APDC

CSO. 1985a. *Statistical Abstract – India* (1984). New Delhi: Central Statistical Organization, Ministry of Planning, Government of India.

CSO. 1985b. Basic Statistics of North Eastern Region. *Statistical Abstract – India* (1984). New Delhi: Central Statistical Organization, Ministry of Planning, Government of India.

Clarke H R, Shrestha R M. 1987 *Traditional Energy Programs and Open Access Forest Resource Management.* Bangkok: Asian Institute of Technology

Clarke R. 1985 Wood-stove dissemination. *Proceedings of the International Workshop on Wood-Stove Dissemination.* Sussex, UK. IT Publications

Community Forestry Development Project (CFDP). 1984. *Introduction of Improved Stoves for Domestic Cooking in Nepal.* Field Document No 10 pp. 14–21. Kathmandu· HMG/UNDP/FAO.

Dhar T N. 1994. *Environment Friendly Hill Development: an Approach for District Chamoli.* Almora: G B Pant Institute of Himalayan Environment and Development.

Dhar T N, Sharma P N (eds). 1987. *Himalayan Energy Systems* Nainital: Gyanodaya Prakashan

deLucia and Associates Inc. 1993. *The Equitable and Efficient Energy Pricing Study* Prepared for Asian Development Bank, Cambridge, MA.

FBSP. 1993 *Pakistan Statistical Yearbook – 1992 and 1993* Islamabad: Federal Bureau of Statistics, Government of Pakistan

Goldemberg J, Johansson T B, Reddy A K N, Williams R H. 1988. *Energy for Sustainable World* New Delhi: Wiley Eastern Limited

Hill K. 1988. *Demographic Trends in China from 1950 to 1982* World Bank Discussion Papers Washington, DC The World Bank.

ICIMOD 1991a *Energy Planning and Management in Kulu District, India.* MIT Series No. 4. Kathmandu International Centre for Integrated Mountain Development

ICIMOD 1991b. *Energy Planning and Management in Kulu District, India* MIT Series No 3. Kathmandu: International Centre for Integrated Mountain Development.

ICIMOD. 1991c. *Energy Planning and Management in Kulu District, India* MIT Series No. 5 Kathmandu. International Centre for Integrated Mountain Development.

ICIMOD. 1991d. *Energy Planning and Management in Kulu District, India.* MIT Series No 6 Kathmandu· International Centre for Integrated Mountain Development

ICIMOD. 1991e. *Energy Planning and Management in Kulu District, India* MIT Series No. 1. Kathmandu International Centre for Integrated Mountain Development

Islam M N, Morse R, Soesastro M H (eds) 1984 Rural energy to meet development needs Asian village approaches. pp. 18–20, 251–265 London. East-West Centre, Resource System Institute, Westview Press

Jodha N S, Shrestha S. 1994. Sustainable and more productive mountain agriculture problems and prospects. *International Symposium on Mountain Environment and Development* Kathmandu: International Centre for Integrated Mountain Development.

Monga P, Lakhanpal T N (eds). 1988 *Rural Energy Alternatives in the Hilly Areas.* New Delhi Today and Tomorrows's Printers and Publishers.

Monga P, Ramana P V (eds). 1992. *Energy, Environment and Sustainable Development in the Himalayas.* New Delhi: Indus Publishing Company.

Munasinghe M, Saunders R J. 1989. *Energy Issues in the Developing World.* Working Papers - Energy Development. Washington, DC: The World Bank.

National Research Council (NRC). 1984 *Diffusion of Biomass Energy Technologies.* pp. 45–60. Washington, DC: Office of International Affairs, National Academy Press.

PCB. 1985. *Statistical Hand Book of Bhutan.* Thimpu: Statistics Division, Planning Commission

PCB. 1987. *Statistical Yearbook of Bhutan.* Thimpu: Central Statistical Office, Planning Commission.

PEP Project. 1995. *Perspective Energy Plan for Nepal* Submitted to the National Planning Commission, Kathmandu

Philips R, Goldemberg J, Johansson T B. 1995. Energy as an Instrument for Socio-Economic Development. New York: United Nations Development Programme.

Pradhan B K, Rijal K. 1988. The role of improved cooking stoves in the national energy scene. Paper presented at the *National Seminar on Improved Cookstove Development and Dissemination in Nepal,* 20–22 January. Sponsored by RECAST and FAO, Kathmandu

Ramani K V, Reddy A K N, Islam M N (eds). 1995. Rural Energy Planning: A Government-Enabled Market-Based Approach, APDC and GTZ, SP-Muda Printing Sdn. Bhd., Kuala Lumpur.

Rijal K. 1987. Critical evaluation of the improved cooking stove program in Nepal. *Renewable Energy Review Journal* 9(1).

Rijal K. 1991. Technology assessment, planning and modelling of rural/decentralized energy systems in Nepal. PhD. Dissertation. New Delhi: Centre for Energy Studies, Indian Institute of Technology

Rijal K. 1994. Economical and environmentally sustainable biomass strategy. *Proceedings of Sustainable Infrastructure Development.* Kathmandu. Nepal Engineers' Association

Rijal K. 1995. Developing wood energy programs and projects Paper presented at the *Regional Training Course in Data Collection, Assessment and Analysis for Wood Energy Planning.* Organized by APDC and FAO-RWEDP, 13–24 November, Kuala Lumpur.

Rijal K. 1996. Rethinking Energy Development Paradigm in the Context of HKH Region (Draft) Kathmandu: International Centre for Integrated Mountain Development.

Rijal K, Manandhar A, Kharel T. 1987 Rural energy planning - participatory action research in selected villages of Nepal *In* Bajracharya D *et al* (eds) Village Voices for Rural Development. East-West Centre/Chulalongkorn University, Hawaii.

Sharma P, Banskota M. 1992. Population dynamics and sustainable agriculture development in mountain area. *In* Jodha *et al.* (eds). *Sustainable Mountain Agriculture,* Volume 1 New Delhi: Oxford and IBH Publishing Co.

Sharma P. 1994. Population and employment challenges in the mountains. *International Symposium on Mountain Environment and Development.* Kathmandu: International Centre for Integrated Mountain Development

NPC. 1993. *Statistical Yearbook of Nepal – 1993* Kathmandu: Central Bureau of Statistics, National Planning Commission

NPC/UNDP. 1995 *Perspective Energy Plan for Nepal.* NPC/UNDP National Execution Project. Kathmandu: NPC/UNDP.

SSB. 1985 *China: A Statistics Survey* Beijing: State Statistical Bureau.

Soussan J, Shrestha B K, Uprety L P 1995. *A Social Dynamics of Deforestation: A Case Study from Nepal.* London. United Nations Research Institute for Social Development, The Parthenon Publishing Group

UN. 1994 *Energy Statistics Year book 1990, 1991, 1992.* New York: United Nations.

UNDP 1991. *Human Development Report.* New York: United Nations Development Programme

UNDP. 1992 *Human Development Report* New York: United Nations Development Programme

UNDP. 1993 *Human Development Report.* New York. United Nations Development Programme

UNDP 1994 *Human Development Report* New York: United Nations Development Programme.

UNIDATA. 1991 *Population Estimates by Province, District and Sub-district* Afghanistan. UNIDATA.

World Bank 1991. *World Development Report.* Washington, DC: The World Bank

World Bank 1992. *World Development Report.* Washington, DC. The World Bank

World Bank 1993. *World Development Report* Washington, DC. The World Bank

World Bank. 1994. *World Development Report.* Washington, DC: The World Bank

World Energy Commission (WEC) 1992. Energy for Tomorrow's World, The South Asia Region, WEC, Madrid.

WECS 1995 *Energy Sector Synopsis Report.* Kathmandu. Water & Energy Commission Secretariat

BIOMASS PROGRAMME IN INDIA: AN OVERVIEW

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Biomass resources for energy use

India is a large country, with a total land area of 328 8 million hectares (mha). It has an estimated human population of 911 million and a livestock population of about 450 million, mainly living in about 587 000 villages. The annual production of foodgrains is about 130 million tonnes (mt). Though there is no authentic data available with regard to the quantity of agricultural and agro-industrial residues, it is estimated to be about 320 mt per annum It is also estimated that the total cattle dung available is about 240 mt per year. About 20% of the total land area is under forest cover, which produces about 40 mt of fuelwood and 4 mt of sawdust.

Taking into account the utilization of a portion of agricultural and agro-industrial residues, and plantations on one mha of wastelands for power generation through bioenergy technologies, a potential of 17 000 MW has been estimated (Table 1).

TABLE 1
Potential/availability of agricultural and agro-industrial wastes

Type of residues	Potential (MW)	Availability (mt)	Quantity required to realize the potential (mt)
Agricultural residues	9500	320	90
Agro-industrial residues	4500	50	45
Energy plantation	3000	93 (mha)	1 (mha)
Total	17000		

The total energy consumption in India has gradually increased from 64.91 mt of oil equivalent (mtoe) during 1973 to 117.52 mtoe by 1983; and to 213.31 mtoe by 1994, indicating a constant growth rate of over six per cent during the entire period. The per capita energy consumption has increased from 108 kilograms of oil equivalent (kgoe) in 1970/71 to about 236 kgoe in 1990/91 which is still very low as compared to the global level. Biomass contributes about 40% of the total energy supply in India. In rural India, biomass contributes about 84% of the energy in the domestic sector. Use of biomass is also significant in many cottage, small, and medium level industries located in rural and urban areas.

Biomass energy technologies

The various technologies for higher production, efficient conversion, and utilization of biomass are listed below.

- Biomass production and improved practices
- Biomass briquetting
- Biomass combustion
- Biomethanation
- Biomass gasification
- Biomass cogeneration

The various R & D, demonstration, and extension programmes based on above-mentioned technologies and their achievements, being implemented by MNES through R & D groups and state nodal departments/agencies, non-governmental organizations (NGOs), and private entrepreneurs are discussed here.

Biomass production and improvement practices

In India, there are 15 different agro-climatic zones. About 93 mha of different types of wasteland are available in these zones. On the other hand, there is an acute shortage of fuelwood and fodder in these areas. With a view to select and develop fast-growing tree and shrub species for fuelwood, biomass research centres have been established in nine different agro-climatic zones. Besides, two R & D projects have been supported in those two zones where centres do not exist. These centres have identified about 70 species suitable for different soil conditions including degraded and marginal lands. A list of institutions and biomass research centres involved in MNES-sponsored R & D projects on biomass production, their agro-climatic zones, and tree species is given in Table 2. Detailed packages of practices, including nursery techniques, have already been finalized for 35 tree species. Biomass productivity assessment studies have recorded yield of 80 tonnes per hectare in *Acacia nilotica*, followed by 76 tonnes in *Cassia siamea*, 70 tonnes in *Leucaena leucocephala*, and 51 tonnes in *Casuarina equisetifolia* in a five-year cycle

TABLE 2
List of institutions involved in R & D on biomass production under MNES sponsored projects in 1995/96

Location of institutions	Agro-climatic region	Fuelwood tree species studied
National Botanical Research Institute, Rana Pratap Marg, Lucknow - 226 001	Upper Gangetic plains	*Acacia nilotica, Prosopis juliflora, Dalbergia sissoo, Populus deltoides*
High Altitude Plant Physiology Research Centre, Garhwal University, Srinagar - 246 174	Western Himalayas	*Alnus nepalensis, Bauhinia retusa, Bauhinia variegata, Quercus incana, Ougeinia dalbergioides*
Department of Silviculture & Agro-forestry, Dr Y S Parmar University of Horticulture and Forestry, Solan, Himachal Pradesh	Western Himalayas	*Celtis australis, Bauhinia variegata, Ulmus laevigata, Acacia mollissima*
School of Biological Sciences, Madurai Kamaraj University, Madurai - 625 021	Southern plateau and hills	*Hardwickia binata, Eucalyptus camaldulensis, Gliricidia sepium*
College of Technology and Agriculture Engineering, Rajasthan Agriculture University Campus, Udaipur - 313 001	Central plateau and hills	*Acacia tortilis, Albizzia lebbek, Prosopis cineraria, Pithecellobium dulce*
Chief Executive, Regional Plant Resource Centre, Nayapalli, Bhubaneswar - 751 012	East coast plains and hills	*Acacia auriculaeformis, Cassia siamea, Casuarina equisetifolia, Sesbania formosa*
TERI, Darbari Seth Block, Habitat Place, Lodhi Road, New Delhi - 110 003	Trans-Gangetic plains	*Haplophragma adenophyllum, Terminalia arjuna, Syzygium cuminu, Melia azedarach*
Department of Botany, University of Calicut, Calicut - 673 635	Western plains and ghats	*Eucalyptus grandis, Macaranga indica, Terminalia catappa, Xylia xylocarpa*
School of Life Sciences, Ravishankar University, Raipur - 492 010	Eastern plateau and hills	*Cleistanthus colinus, Lagerstroemia parviflora, Peltophorum deltoides*
Department of Botany, Vishwa Bharti, Ratnapalli, Shantiniketan - 731 235	Lower Gangetic plains	*Acacia moniliformis, Artocarpus heterophyllus, Alstonia chilensis, Schleichera trijuga*
Centre for Eco-development, North-eastern Hill University, Shillong - 793 014	Eastern Himalayas	*Pinus caribaea, Gmelina arboria, Albizzia falcaterria*

Higher yield has been recorded in male plants of *Casuarina equisetifolia* as compared to female and hermaphrodite plants.

Biomass centres have been providing quality seeds and seedlings and training on energy plantation to fuelwood growers, local people, and representatives of government organizations and NGOs in their respective zones. Under the energy plantation programme supported by the Ministry during 1986 to 1992, about 17 000 hectares of degraded lands have been covered, and the survival rate has been as high as 85% Fuelwood plantation has

also been supported by the Ministry of Environment and Forests, and the Ministry of Rural Affairs and Employment, under their respective schemes.

Biomass briquetting

Biomass materials, except wood, are loose materials having low bulk densities, and, therefore, are inconvenient and uneconomical to handle, transport, and store. Direct use of these biomass resources is associated with inefficient burning and pollution problems. Biomass briquetting is a techno-economic solution for these problems. Biomass briquettes have calorific value ranging from 3400–4200 kcal/kg depending upon the raw materials used The ash content is only 8–20%. It is equivalent to 'B' grade coal in terms of calorific value They also do not emit any harmful substances like SO_2 or NO_2 during combustion.

In India, about 70 biomass briquette machines, using the die and punch, ram and die, and screw technologies have been installed in the private sector. These machines have the capacity of 250 kg/tonne/hour and are using agricultural and agro-industrial residues. The briquettes produced are being marketed for use in tea drying, boilers, hotels, etc. The Indian Renewable Energy Development Agency (IREDA), a financing agency under MNES, is providing soft loans to the briquetting industry. There are seven biomass briquetting machine manufacturers in India, who mainly make the piston or ram type press. Some prototypes of the screw press type of briquetting machines have also been developed.

Biomass gasification

Biomass gasifiers convert solid biomass materials such as wood and agricultural and agro-industrial residues into producer gas through a thermo-chemical process. The producer gas can either be burnt directly for thermal applications or be used for replacing diesel oil in dual-fuel engines for mechanical and electrical applications. The Programme on Biomass Gasification encompasses R & D and demonstration. Four biomass gasifier action research centres (ARCs) have been supported by the MNES at the Indian Institute of Technology (Delhi and Mumbai); the Indian Institute of Science, Bangalore; and the Madurai Kamaraj University, Madurai. These centres are engaged in R & D on gasifier systems and sub-systems, characterization of biomass, testing and evaluation of gasifiers, and training and awareness.

Five biomass gasifier industries are manufacturing gasifiers for mechanical, thermal, and power generation applications. MNES has been supporting a market-oriented biomass gasifier demonstration programme So far, about 1500 gasifiers, of a total capacity of 22 MW equivalent, have been installed for various applications for individual community and industrial uses. The uses are water pumping, thermal energy in plywood and other industries, and power generation for captive use, as well as rural electrification (Table 3). About 10 villages have been electrified through biomass gasifiers.

TABLE 3

Gasifier systems installed (June 1996)

State	1993/94				1994/95				1995/96			
	No of systems sanctioned	Capacity	No of systems installed	Capacity	No of systems sanctioned	Capacity	No of systems installed	Capacity	No. of systems sanctioned	Capacity	No of systems installed	Capacity
Andhra Pradesh	20	401	18	390	27	2800	24	2400	78	3865	17	1700
Arunachal Pradesh	10	320	3	120	—	—	—	—	—	—	—	—
Assam	—	—	—	—	7	36	5	23	—	—	—	—
Goa	—	—	—	—	—	—	—	—	3	115	—	—
Gujarat	22	1338	14	1030	23	2684	12	1104	9	278	5	162
Haryana	1	100	1	100	13	1328	8	590	14	1280	—	—
Karnataka	—	—	—	—	—	—	—	—	2	15	—	—
Kerala	1	100	1	100	4	400	4	400	—	—	—	—
Madhya Pradesh	22	185	10	100	33	9818	14	1740	36	2020	10	1500
Maharashtra	2	140	1	40	6	309	3	110	1	500	1	500
Orissa	—	—	—	—	—	—	—	—	1	10	—	—
Punjab	38	1005	4	90	22	1710	3	150	—	—	—	—
Rajasthan	12	376	9	165	—	—	—	—	—	—	—	—
Tamil Nadu	3	107	—	—	1	300	—	—	1	40	1	40
Uttar Pradesh	—	—	—	—	1	150	1	150	—	—	—	—
West Bengal	—	—	—	—	—	—	—	—	5	500	5	500
Total	131	4072	61	2135	137	19535	74	6667	150	8623	39	4402

Biomass combustion

With a view to utilize the surplus quantity of agricultural and agro-industrial residues, a programme on biomass combustion-based power generation at the *taluka* level has been launched during the year 1994/95. The programme supports preparation of a detailed project report and provides a capital subsidy of Rs 3.5 crores per project of 10 MW capacity level for a few demonstration projects. The other scheme under the programme provides interest subsidy for a capitalized grant of up to Rs 17 lakh/MW for projects of more than 5 MW capacity each, to be provided to the financial institutions for reduction in interest rates on the term loans. Two projects of 6 and 5 MW capacity are under installation in Madhya Pradesh and Andhra Pradesh under the programme. Ninety-six biomass assessment studies have also been undertaken in the various states of the country.

Biomass cogeneration

MNES has been implementing a National Programme on Bagasse-based Cogeneration for promotion of surplus power generation through optimum cogeneration in sugar mills. A potential of around 3500 MW of surplus power generation has been estimated. The programme is oriented towards providing special dispensation to sugar mills in the cooperative/public sector. Under the programme, three schemes, namely, the capital subsidy scheme, at the rate of Rs 70 lakhs/MW of surplus power fed by the sugar mill into the grid subject to a maximum of Rs 6 crores for each for first 12 projects (nine projects shall be in cooperative/public sector sugar mills); the interest subsidy scheme, which provides a grant of maximum of Rs 20 lakh/MW of surplus power fed into the grid by a sugar mill to enable the provisions of financial institutions to reduce interest on term loans by around two per cent; and 50% cost for the detailed project report preparation with an upper limit of Rs 4 lakhs. Under the programme, seven projects, with an aggregate capacity of about 30 MW, have been commissioned in Tamil Nadu, Maharashtra, and Uttar Pradesh.

Improved cookstoves

Improved cookstoves (*chulhas*) developed by various R & D groups have a heat-transfer efficiency of 20 to 40%, as compared to the 8–10% in traditional *chulhas*. A National Programme on Improved *Chulhas* was launched in 1984/85, and is being continued during the Seventh and Eighth Five Year Plans. Under the programme, 80 different models, both fixed and portable type cookstoves, are promoted in all the states and union territories of the country. The programme is being implemented through governmental organizations and NGOs The provisions under the programme are: a fixed amount of subsidy up to 50% of the capital cost; support for publicity, awareness, and training courses; support for organizational infrastructure to the implementing department/agency; incentive to self-employed workers; and dealership support for fair price shops and cooperative stores. So

far, about 26 million improved cookstoves have been promoted under the programme, with about 2.5 million improved cookstoves added each year.

Improved cookstoves provide economic benefits in terms of saving of fuelwood, which is estimated to be about 700 kg of fuelwood per stove per year, besides other benefits such as reduction in drudgery of women and girl children, employment opportunities to rural entrepreneurs and artisans, etc.

Biogas

Biogas is a clean, non-polluting, smoke-free, and inexpensive fuel produced from cattle dung, human excreta, and other organic matter through anaerobic digestion. The manure value of the digested material also gets enhanced in the process. Simultaneously, many social benefits accrue by using biogas such as improvements in the rural sanitation, environment, health, and hygiene, and reduction in the drudgery of women and children who are mainly involved in the collection of wood from long distances. In view of its multiple benefits, a National Project on Biogas Development was launched in the year 1981/82. So far over 2 3 million rural families have been covered under the project. The programme has generated demand, and about 200 000 more biogas plants are being added on every year Community, institutional, and night soil-based biogas plants are also promoted by MNES, by providing them financial support.

Energy recovery from municipal and industrial wastes

Urban and industrial wastes, both solid and liquid, are another large source of bioenergy. These sources can offer a viable option for energy generation with the attendant benefits of reducing emissions of greenhouse gases and minimizing environmental degradation. In the past, a number of R & D projects at various institutions were sponsored by MNES, and the experience gained has made it possible to scale up and demonstrate technologies to utilize these wastes for recovery of energy A potential of more than 1700 MW has been assessed The Ministry has also launched a programme for the recovery of energy from urban and industrial wastes, under which financial support and incentives are provided. In addition to this, emphasis is also being given to the setting up of 16 projects covering selected substrates, namely community sewage and effluents from leather industry, abattoirs, pulp and paper industries, vegetable markets, etc., under a United Nations Development Programme assisted project. A National Bioenergy Board has been established to guide, review, and direct the programme.

Fiscal incentives

A number of fiscal and financial incentives are available for bioenergy and other renewable energy technologies to the manufacturers and users. Barriers for participation of the

private industry and international manufacturers in setting up of manufacturing facilities, or supply of equipment, materials and products, etc., have been removed. Financial and technical collaborations are encouraged. There are a host of benefits available to both manufacturers and users of renewable energy systems. These include: (i) 100% depreciation for tax purposes in the first year of the installation of the systems; (ii) no excise duty on finished products; (iii) low import tariffs for capital equipment and most materials and components; (iv) soft loans to manufacturers and users by IREDA, and (v) remunerative price for the power generated through renewable energy systems, fed to the grid, by the state electricity boards.

BIOMASS FUEL CONSUMPTION AND FORMULATION OF HOUSEHOLD ENERGY STRATEGY IN PAKISTAN

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Overview of the energy sector

Pakistan is endowed with large natural gas resources discovered in the early 50s. Similarly, oil and coal reserves have also been discovered, and hydro-electric potential has been tapped to meet the energy needs in the country. However, even with these natural endowments, Pakistan is dependent upon imported supplies, mainly in the form of crude oil and finished petroleum products from the nearby Gulf countries. While the consumption of modern fuels is growing, a large proportion of households (mainly in the rural areas) are still using traditional fuels (firewood, crop residues, and animal wastes) for a variety of socio-economic reasons. Energy consumption levels are generally low (often at subsistence levels) compared to other developing economies, reflecting the poor economic condition of a majority of the population. The current national energy consumption of modern fuels is estimated at over 20 million tonnes of oil equivalent (mtoe) (at the end-consumption level), which has been growing annually at 6.1% over the last five years. Of this, approximately two-thirds is supplied through indigenous resources at the primary-supply level, while the remaining is imported mainly in the form of crude oil and petroleum products. In recent years, the cost of imported energy has been $1.5 billion, almost 40% of the total export earnings of the country.

Traditional fuels (firewood, crop residues, and animal wastes) are the primary source of energy for a majority of the rural population in Pakistan. Reliable statistics on the consumption of traditional fuels are not available, since these are not widely traded in the market. However, it is estimated that traditional fuels supply an additional 20 mtoe of

energy, primarily to the household sector. The consumption of these fuels takes place very close to the supply sources.

The household sector accounts for approximately 54% of the final energy consumption in Pakistan, and is thus the largest single energy-consuming sector in the country. Because of rapid population growth, it is also the faster-growing sector in terms of the demand for modern fuels. This growth has placed a tremendous stress on the modern fuel supply infrastructure, resulting in electricity load shedding, natural gas rationing, fuel shortages and increased requirements for fuel imports, and massive capital investments in the energy sector. At the same time, and in spite of the growth of modern fuel usage, the majority of households continue to rely on biofuels. Each of these biofuels alone supplies more energy (in terms of their latent value) to the household sector than all the modern fuels combined. In view of the rapidly growing population, there have been fears that wood-fuels were becoming scarce, causing hardship, particularly to those low-income households who depend exclusively upon the collection of those fuels as 'free' goods to meet their basic energy needs.

The UNDP/World Bank project

It is in this background that the major demand analysis survey was conducted under the Household Energy Strategy Study (HESS) Project over a period of one year, and collected energy and socio-economic information for the World Bank's Living Standards Measurement Study. The primary objective of this survey was to develop energy consumption patterns and causal relationships, using the cross-sectional database. Satellite imagery, in conjunction with extensive field surveys, was utilized to take stock of the biomass resources, using variable sampling plots in different agro-ecological zones. Finally, extensive nationwide surveys were launched to trace the flow of wood-fuel (and timber) from producers, wholesalers, transporters, retailers, and to the end-consumers. This survey enabled the project team to highlight the impediments in the wood-fuel marketing system, and to propose different policy options. A Residential Electricity Consumption Survey (RECS) was conducted by installing loggers for one/seven days period to understand the consumption patterns and the contribution of the household sector to overall system peaks. These surveys were completed with the help of local professionals, staff of the counterpart agency, and specialists of the Energy Sector Management Assistance Programme (ESMAP). Databases were subsequently developed, and analytical work undertaken to formulate an integrated household energy strategy for Pakistan.

Sectoral fuel consumptions

Survey results indicate that the household sector accounts for approximately 54% of the total final energy consumption in Pakistan, equivalent to approximately 20 mtoe in 1991. Table 1 shows the breakdown of total final energy consumption by different fuels and all the sectors, including households It will be observed that biofuels account for 86% of the total household energy consumption in Pakistan, while firewood alone accounts for 54% of

TABLE 1

Final energy consumption by sector: 1991 ('000 toe)

Sector	Electricity	Gas	LPG[a]	Petroleum production	Modern fuels	Coal/ coke	Wood	Dung	Crop residues	Traditional fuels	Total fuels
Households	851	1416	92	442	2801	119	10637	3613	2816	17185	19987
Commercials	190	275	31	522	1018	0	713	0	0	713	1731
Industrial[b]	905	3290	0	1124	5319	2878	5	0	1353	4236	9555
Agriculture[c]	458	0	0	1634	2092	0	0	0	0	0	2092
Transport[c]	3	0	36	3729	3768	1	0	0	0	1	3769
Other/government	148	0	0	335	483	1	0	0	0	1	484
Total	2555	4981	159	7786	15481	2999	11355	3613	4169	22136	37618
Unit household consumption/year	1238 kWh	40 2 mcf	122 kg	41.1 litre	—	115 kg	2324 kg	1477 kg	1161 kg	—	—

[a] consumption figures for LPG in commercial and road transport sectors based on Energy Wing estimates; [b] excludes 1.26 mtoe of natural gas used in fertilizer industry as feedstock; [c] petroleum products consumption in transport and agriculture sectors estimated by the Energy Wing.

Note. Firewood consumption for the commercial sector estimated by HESS at 1.9 million tonnes (*mt*).

Sources. UNDP/GOP (1991): HESS estimates for the household sector; Energy Wing estimates for other sectors.

the total Biofuels are principally used by households in traditional stoves to meet the bulk of their cooking, space-heating, and water-heating needs. Natural gas, used mainly for cooking in urban areas, is the most important modern fuel, accounting for over half of the total modern fuel consumption in the household sector. Electricity, used for lighting and space cooling, accounts for a further 30.6%, followed by kerosene (15.7%), which is mainly used for lighting, but also for some cooking. The remaining 3.2% is accounted for by liquefied petroleum gas (LPG) use, which has so far remained fairly small in Pakistan. No significant use of coal in the household sector of Pakistan was found during the survey.

Wood supply

Of the total energy consumed by the household sector, a predominant proportion comes from wood and other biomass resources such as dung and crop residues. Evidence suggests that such heavy reliance on these fuels has a number of undesirable consequences, including environmental damages. The Biomass Resource Assessment component of the project is aimed at developing a database which would include, *inter alia*, the availability and supply of traditional fuels to the household sector.

For this purpose, a national agro-ecological zonation was created using multi-temporal advanced very high resolution radiometer (AVHRR) satellite imagery to distinguish between patterns of vegetation activity with time. The satellite imagery was obtained as monthly composites of daily images covering six annual growing seasons from 1982–87, then combined with ancillary geographical information system (GIS) data on rainfall, topography, climate, and the extent of irrigated farmland to produce a zonation of 14 land cover types for the whole of Pakistan (Table 2). This zonation provided a national

TABLE 2
Agro-ecological zonation

Zone	Description	Area (km²)	Fraction (%)
1	Hyper-arid desert	58738	6.7
2	Arid desert	193604	22.1
3	Transitional arid/semi-arid rangelands	117833	13.4
4	Moderate productivity semi-and	74819	8.5
5	High productivity semi-arid	61180	7.0
6	Sub-tropical rainfed agriculture	27878	3.2
7	Permanent snow	25019	2.9
8	High mountain valleys	18964	2.2
9	Alpine and temperate scrub/forest	94747	10.8
10	Temperate/sub-tropical Himalayan foothills	10637	1.2
11	Marginal irrigated	1940	0.2
12	Moderate productivity irrigated	74533	8.5
13	High productivity irrigated	111717	12.7
14	Indus delta swamps	5691	0 6
	Total	877227	100.0

Source UNDP/GOP (1991).

sampling frame to link the supply and demand components of the project, and to provide a valid basis for extrapolating the results of the supply survey to the national level.

Sampling plan for woody biomass

Multi-stage sampling was used for the biomass supply survey to maximize efficiency The agro-ecological zonation developed from the AVHRR imagery provided the first stage of a multi-stage sampling frame. The second stage consisted of 12 scenes of Landsat Thematic Mapper (TM) imagery for a more detailed classification of the vegetation. Sampling units were then selected by variable probability sampling from the digital vegetation classification from each Landsat scene, for field measurement of woody biomass and crop residues. Field teams were given precision-corrected satellite images and topographic maps to guide them accurately to each sampling unit.

Standing wood stock and annual productivity

The sampling methodology ensured that sampling units fell in areas of woody biomass vegetation in all agro-ecological zones throughout Pakistan. All woody biomass was measured, including commercial timber trees, other tree species, and woody shrubs Mathematical models were also developed from destructive sampling of trees and shrubs to predict their biomass content by component (commercial timber, poles, large branches, small branches, twigs, and leaves). Models were also developed to allow for the effects of crown damage due to lopping on tree biomass and growth. In order to estimate annual sustainable productivity, models were developed for trees and shrubs using both primary data from growth measurements in the field, and secondary data from forestry yield tables. Wood biomass resources, and annual productivity, was estimated for each agro-ecological zonation, and for different provinces. The main results are given in Table 3.

Sustainability of forest resources

The issue of biomass sustainability is complex, and cannot be addressed only from the consumption viewpoint. It should also be seen from the viewpoint of the producer, and the relationship of supply and equilibrium prices have to be taken into account. The real importance of biomass sustainability lies in the associated issues of higher demand resulting in higher prices, which, in turn, could increase the wood-fuel share of the household budget, stimulate interfuel substitution, reduce wood-fuel consumption, or induce some combination of the above effects. The sustainability of forest resources has a profound

TABLE 3
Annual productivity of wood biomass resources

Resources	Productivity (mt)
Total standing stock	210.78
Total annual wood growth	22.70
Total fuelwood growth	20.13
Twigs/leaves growth	10.10
Roundwood-fuel growth	10.03

impact upon the groundwater recharge, soil erosion and fertility, microclimate quality, and the fragile ecosystems.

Agricultural residues

An agricultural residues survey was carried out to cover the cotton, sugarcane, maize, rice, and wheat crops, both for the *rabi* and the *kharif* seasons. Samples were drawn from different areas in accordance with the agro-ecological zonation, and for different productivity conditions. These samples were even dried under specified conditions, and their resultant residual fuel values were carefully calculated. Ratios between crop size and the agricultural residues were developed, and estimates for different agro-ecological zones, and at the provincial levels, were made. The estimated quantities of crop residues are given in Table 4.

Cotton sticks are most commonly used as fuel by the households. Bagasse, as a by-product of the sugar-making process, is used as industrial fuel by the industry itself. The remaining residues are generally used as fodder for the cattle rather than fuel. Agricultural residues are also used as soil conditioners by the farmers, and, therefore, the net amount available to be used as fuel is much smaller than the overall availability.

Existing wood-fuel trading structure

Firewood markets in Pakistan operate under an organized set of arrangements and structures, which are responsive to supply and demand conditions. The actual scale and efficiency of trading networks are regulated by a number of interacting factors such as local demand, transport requirements, supply locations, and prices. The manner in which traders cope with these factors is a function of certain basic features of their trading establishments. About 40 412 businesses operate in firewood markets throughout Pakistan, of which roughly 32% are found in urban centres, 52% in villages, and the remaining 16% are located along metalled roads. In addition, about 4800 timber traders also sell wood, though at lower levels Retailers dominate the firewood market in numerical terms, totalling over 36 000 or 91%. Sales to the household and commercial sectors comprise the bulk of their revenue. Retailers are unevenly distributed throughout the country with the highest percentages found in Punjab and in the North West Frontier Province (NWFP).

TABLE 4
Estimates of crop residues

Crop residues	Quantity (mt)
Cotton sticks	12.46
Maize	3.47
Sugarcane (bagasse)	12.88
Rice	8.16
Wheat	20.65

Most traders sell retail as well as wholesale. There are a few 'pure' retailers or wholesalers who sell exclusively to either households or other traders. About 65% of all traders recorded sales to each of the three types of buyers, forming the backbone of the market. Roughly 30% concentrate solely on the household sector, while only five per cent target other traders exclusively.

Firewood trading businesses are generally small-scale operations that remain open year-round. About 71 848 people were working on a permanent basis during the winter of 1992, roughly 87% in retail. A further 26 928 people were employed as part-time staff Approximately half of all traders also stock other fuels and materials for sale. Primarily, these products include timber, its sawdust derivatives, and charcoal. Most of the traders, who also sell timber, are located in the NWFP and Punjab provinces, where they have easier access to public auctions of timber from government forests. Seasonal variations are in clear evidence for the firewood trade. Winter sales are roughly twice the level of summer sales. Seasonal variations are more pronounced for retailers, whose summer trading activity drops to approximately 38% of winter sales while only dropping to about half for wholesalers. Monthly expenses per trader depend on location and type of trader. Wholesalers have roughly double the monthly expenses as retailers. Urban wholesalers pay higher rents than any other type of trader. Rural wholesalers show a disproportionately higher monthly budget for temporary staff.

Supply distribution chain

Most rural-based wholesalers obtain their supplies directly from private farmers, confirming the importance of these supply sources to the firewood trade. Urban retailers have the shortest distribution chain, as most do not venture into rural areas to procure their supplies, preferring instead to buy from large wood depots located just beyond municipal borders, or from local wholesalers. According to trader perceptions, supply problems exist particularly for those located along the metalled roads. This suggests that wood markets are inter-dependent, and competition for limited winter wood stocks is keenest for all but the urban retailers, most of whom do not buy directly from private farms. Unlike other commercial products, firewood has no easily traceable standard distribution route. It is supplied from either private wood producers or government forests. Upon entry into the market, it weaves its way to the final consumer after a number of intermediate levels of exchange between traders.

Private farmers in Punjab are crucial players in the supply to firewood markets, constituting nearly 90% of all who sell their wood to local traders. Wood producers generally tend to be large landholders. About 75% of the farmers surveyed indicated that they planted the trees themselves, and the predominant species planted are *Shisham* and *Kikar*. There is only marginal involvement of tree producers in the inner network of the firewood trade. Their role is primarily that of resource supply preferring to leave the actual parameters of wood market entry up to the traders, which puts them at a disadvantage. Except in Baluchistan, most farmers sell their wood on a standing tree basis. The sale prices of wood producers vary on the basis of tree type and quantity sold. The price for all sales ranged from Rs 125–1000/tonne, with an average price of about Rs 450/tonne. *Babul* prices are the lowest, fetching about Rs 350/tonne, while assorted other species fetched roughly

50% higher prices (Rs 530/tonne). Most of the wood sold in a province originates in the same province. This situation holds true for every province except Baluchistan, where firewood is drawn mostly from the neighbouring Sindh province. This pattern of cross-province transport reflects the physical scarcity of wood resources in this province.

Sales structure

Winter monthly firewood sales were 1.822 mt during 1992. This amount included 1.43 mt that were sold directly to the final consumer as well as 0.392 mt that were sold to other traders On an annual basis, the wood trade in Pakistan approached 16 mt during 1992, or roughly 135 kg/capita/year. The sale structure of wood markets is retail-dominated. Annually, about 12.4 mt are sold to the final consumer, compared to the 3.4 mt sold to other traders. For retailers, the wholesale portion of monthly winter sales was almost zero for NWFP and Baluchistan retailers. For wholesalers, the retail portion of winter monthly sales is roughly a quarter of their trade. Most of the wood trade is taking place in the northern part of the country. Of particular note is the situation in rural areas of NWFP, where retailers account for 56% of the total sale to rural consumers.

There are significant variations in purchase prices across provinces. This range extends from the lowest price paid by Sindh traders to the highest purchase price paid by traders in large urban centres. These fluctuations tend to even out when considered from the perspective of trader location. There is a general consistency in purchase prices for urban, rural, and roadside dealers. Each is within 6% of the national average, indicating a competitive market system. Selling prices also show significant variation across provinces. Except for Baluchistan, price mark-ups are fairly consistent throughout the country, coming to roughly 30%. For the case of Baluchistan, this mark-up can probably be explained by the higher transport costs involved and the attendant risks. Net margins show considerable variation per province and trader location. Sindh traders show the lowest profit margins at Rs 23 000, while Baluchistan traders show an uncharacteristically high annual net margin at Rs 108 000.

Firewood transportation

The most common form of wood transport is by truck, of which there are about 100 000 in the country. Most of these are employed in a wide variety of transport items in addition to firewood. The trucking agencies which are heavily involved in wood transport tend to be small to medium sized, and remain busy throughout the year. The most common truck is a six-wheeler Bedford with an eight-tonne hauling capacity. Wood transporters are characterized by a relatively recent entry to wood markets. There are wide variations between agencies regarding the number of trucks contracted out for wood transport. Most carry out between one and eight wood hauling trips per month and average about 512 km/month. About 50% of the wood transported is generally medium diameter round logs. Most of the remaining are large diameter round logs. The transport of firewood involves substantial distances and freights. Baluchistan traders show the highest average distance travelled. Punjab traders, regardless of location, show the lowest average transport distance. This is due to the fact that they are in close proximity to farmlands from where they obtain the overwhelming majority of their supplies

Transport costs figure prominently in the price structure of firewood. Accounting for 67% of *en route* and yard arrival costs. Costs are the lowest for roadside traders operating closer to farm sources. The tariff structure used by transport agencies includes a fixed overhead and a distance-dependent freight cost. Average wood transport costs are estimated at Rs 0.53 per tonne-kilometre for a fully loaded eight-tonne truck. Transit taxes show wide variations across provinces. *Zilla* and octroi taxes vary from 9% in Sindh to 34% in Punjab. The lowest percentage of taxes are paid by rural traders (12%); yet it is not significantly different from the share paid by urban traders (17%), who may transport their supplies across *tehsil* and municipal boundaries. Compared to other costs, overall transit taxes take up the same share (16%) as costs involved in unloading and other yard arrival tasks. The fluctuations in transit taxes undoubtedly affect the price structure throughout the country.

Future role of biomass energy

Household energy projection model

An analytical demand projection model was developed based upon the HESS survey, and is structured upon the disaggregation of households into five groups representing principal energy consumption patterns These groups correspond to rural/urban location, use of electricity, and use of natural gas. Relationships between fuel consumption, and other demographic and economic data were statistically derived from the HESS database for each of these groups. Residential energy consumption patterns evolve as households move between groups, and as average household behaviour changes within groups. This evolution occurs in response to changes in the independent demographic and economic parameters. Some of these demographic and economic drivers consist of exogenous variables outside the domain of government energy policy (population growth, rural/urban migration, changes in household size, household expenditure growth, etc.), and are modelled probabilistically. Other drivers represent government policies, such as fuel prices, gas and electric connection rates, and appliance efficiency standards, and are modelled as user-defined choices.

Demand scenarios

Four different scenarios for estimating the long-term energy consumption for the household sector were taken: (i) a baseline scenario; (ii) an accelerated natural gas and electricity connections scenario, (iii) an economic pricing of natural gas and electricity scenario; and (iv) an improved electric end-use efficiency scenario. The baseline scenario assumes the continuation of current policies, i.e., the number of new gas and electricity connections is according to Government of Pakistan (GOP) targets (adjusted according to actual achievements in the past), LPG network in rural areas assumed at current level, kerosene and LPG prices bearing the same relationship to crude oil as in 1991, and prices of other fuels remaining unchanged in real terms. Under the accelerated connection scenario, the number of new gas and electricity connections is increased by 10% over the baseline case, up to a maximum of 95% electrification/gas connection levels. Under the economic pricing scenario, gas tariffs are doubled by 1998 (in constant 1991 terms), and increases these

to 60% of economic cost by 2003 (at expected crude oil prices, this value is approximately Rs 105 per mcf), and, subsequently, increases these to parity with economic costs by 2008. Similarly, for electricity, the average tariff is increased to Rs 1/kWh in 1998, and to parity with economic costs (a levelized Rs 1.67/kWh) by 2003. Under the improved efficiency scenario, certain assumptions were made on efficiency improvements (and hence lower unit consumptions) for lighting, fans, and refrigerators.

Demand projections for baseline scenario

Table 5 presents energy demand projections up to 2008 for the baseline scenario, based upon a number of macro-economic, exogenous, and policy variables, transition among different consumption groups, and consumption patterns of these groups.

Trends and transitions

The significant trends in household energy consumption, and inter-fuel transitions are given below.

1. Electricity consumption increases by nearly 350% between 1991 and 2008, with increasing incomes accounting for only about 15% of the increase, i.e, if no more connections were added, total household electricity consumption would be expected to grow by about 50% over the same period; connection rate is the principal driver of this increase.
2. Natural gas consumption follows a similar trend, as per household consumption among users increases only by 20%, but the increase in connections facilitates the bulk of the 365% increase in total consumption.
3. Alternatively, the increase in LPG consumption is driven primarily by the increase in household incomes, as increasing incomes allow households to move quickly from

TABLE 5
Household sector final energy demand

Fuel	1991 estimate	1991–93	8th Plan (1993–98)	9th Plan (1998–2003)	10th Plan (2003–08)	1991 Actual	Percentage error in 1991 estimate versus actual
Electricity (GWh)	9923	11552	16527	23987	34440	10455	-5.1
Natural gas (mmcft)	55815	64980	95259	139675	203724	60531	-7.8
LPG (mt)	88714	112360	189525	298165	422126	85242	+4.1
Kerosene (million litres)	565	596	621	642	682	564	+0.1
Firewood ('000 mt)	29913	32217	38582	44605	51111	29380	+1.8
Dung ('000 mt)	12879	13585	15338	16796	18186	13309	-3.2
Crop residues ('000 mt)	8389	8709	9508	10254	11174	8301	+1.1

Source GOP (1993).

kerosene to LPG, or skip kerosene altogether as a cooking fuel and move directly from wood-fuel to LPG.

4. Although there is some increase in wood-fuel use per household (of the order of 15–25% depending upon the group), the 71% increase in total wood-fuel consumption is primarily attributable to population growth, and the remaining growth in total consumption appears to be a result of interfuel substitution away from crop residues and dung, facilitated by income growth.
5. Dung and crop residue use remains constant (or falls depending on the group) on a per household basis; however, population increases cause 41% and 33% growth in total consumption, respectively.
6. Approximately 65% of the households will continue to cook with biomass (though not exclusively), compared to 80% today, and biomass will remain an important component of the household fuel mix in Pakistan.

Household energy strategy

Objectives

Based upon the results of different surveys, and the household energy issues, a 10-year household energy strategy is being outlined which would assure balanced and sustainable development of this sector. The basic principles of the proposed strategy are listed below

1. Continue to offer households a broad choice of fuels for different end uses, and there should be no forced government intervention for inter-fuel substitution.
2. Irritants (government controls, levies) must be removed, so that the energy market could operate on a more competitive basis.
3. The largest possible participation on the part of the private sector and the community must be obtained implementing the strategy, and the government must restrict its role as the facilitator.
4. Seek alternative household energy systems and fuels that are of lowest economic cost to the country, and also ideally result in economic advantage to the households.
5. Action essential to partially replace firewood as a household fuel, so that regional imbalances and threat of deforestation could be averted.
6. Maintain prices of petroleum products, natural gas, and electricity for the household sector at their true economic values, but keeping into account the welfare considerations of the poorer sections of the society.
7. Rational use and energy efficiencies in the household sector must be promoted through a system of incentives.
8. The household energy strategy must be institutionalized in the overall planning system, and progress monitored on a periodic basis.

Strategy components

The household energy strategy consists broadly of the mechanisms for managing and orienting energy supplies, the mechanisms for managing and orienting energy demand, and

the institutional and community elements and/or agents participating in the promotion and implementation of the strategy. These mechanisms and institutional and community elements act in an integrated and complementary manner to achieve the overall objectives of the strategy. Within this broad framework, four specific programmes encompassing these components are as follows: (i) overall demand management and prices; (ii) sustainable supplies and fuelwood production; (iii) commercial fuels infrastructure and interfuel substitution; and (iv) institutional development.

Overall demand management

Demand-side management

Both HESS and RECS have indicated the potential for demand-side management (DSM) measures to rationalize the peak load demand of the household sector. Shifting of certain household loads (water pumps, electric iron, etc.) from the morning-peak to non-peak hours can result in flattening the demand curve. The government had also experimented with the daylight savings programme, and its results on the peak load demand should be carefully evaluated. As DSM for households has to be voluntary, awareness campaigns and outreach programmes have to be organized to educate households in reducing their consumption, without any sacrifice of welfare. Advisory services on building construction, insulation, etc., need to be provided along with recommendations on installation of electric and other equipment, and its efficient utilization.

End-use efficiency improvement and equipment standardization

The study findings suggest that the introduction of high-efficiency appliance programmes is economically justified for most appliance utilizations. Economically justified measures for lighting, refrigerators, and fans could, by the year 2008, reduce the economic cost of residential electricity supply from approximately Rs 58 billion to Rs 48 billion in 1991 terms. This estimate of total technical potential takes into account the penetration rates expected under an aggressive appliance efficiency programme. Similar programmes for natural gas/LPG and kerosene equipment standardization and end-use efficiency improvement would result in rich dividends to the economy.

Efficient fuelwood stoves

Since fuelwood consumption represents a large proportion of the household energy mix, efficient woodstoves offer great potential for rationalizing consumption and bringing it in line with supply. However, this option has not made a great deal of progress primarily due to the following reasons: (i) efficiency programmes have generally underestimated the efficiency of the open-hearth or traditional *chulhas*, with the result that fuel-efficient stoves do not demonstrate the promised savings; (ii) designs of the fuel-efficient stoves are actually less-efficient than open fire (in particular, the bodies of the high-mass smokeless stoves absorb too large a share of the heat to be as efficient as simpler metal bucket design); and (iii) inconvenience involved in using the fuel-efficient stoves. A designated agency should formulate and coordinate a fuel-efficient stove programme for the household sector, keeping in view the experiences gained so far and the above factors as well.

Energy pricing for demand management

The findings of the study suggest that it should be possible to design a tariff structure in which retail electricity and gas prices increase substantially by 1998, and reach economic parity by 2003 (for electricity) or by 2008 (for natural gas), and no income category will face an increasing fuel budget share. Increasing tariffs will not only dampen demand (and thereby reduce the economic costs of electricity and gas consumption), but will also improve the financial viability of electric and gas utilities in Pakistan. Also, the number of slabs in the domestic sector electricity and gas tariffs should be reduced, fuel adjustment surcharge (FAS) needs to be made adjustable, and flat rates done away with.

LPG pricing policy should be sensitive to gas pricing and availability, but should increasingly reflect its own market characteristics, as gas prices are rationalized. LPG prices should be maintained at the import parity level, and regularly adjusted to reflect the actual import versus domestic supply balance. The current relatively high import price, allowed as a basis for fixing a retail price, provides incentives to increase both imported and domestic supplies, and for suppliers to finance necessary cylinder, transport, and storage/distribution costs from the profits realizable on LPG sales. Once the consumer cylinder and appliance costs are overcome, the LPG cost (at higher levels) has been shown to be relatively competitive with other fuels. For domestic LPG supplies, producers should be encouraged by allowing import-equivalent price levels and by adding incentives for remote locations. For downstream bottling and distribution activities, tax credits and related price incentives should be established to stimulate investments by the private sector in bottling, transport, and storage facilities. Also, price determination should be made only at the regional terminal level, and not downstream through marketing to the final consumer. A regional wholesale price reference would allow supplies to move more effectively in response to profit incentives and reduce the unreported market. This policy should, however, be accompanied by efforts to limit allowable final price levels, and to monitor competitive practices to ensure that market abuses are not occurring in the transition.

Kerosene price levels should be formally linked to a crude oil plus refining/distribution cost equivalent level, with regular adjustments made in response to import market conditions Prices should be increased to parity with diesel, and otherwise 'marked-up' over crude oil cost sufficiently to recover kerosene's contribution to the necessary investments in refinery expansions and upgrades required to meet market demand. As with LPG, price determination should be done only at the regional depot level. A kerosene pricing structure, more reflective of regional cost differences, will encourage supplies to move to their highest value market, and stimulate inter-fuel competition and conservation in the process.

Sustainable supplies and fuelwood production

With careful management and planning, fuelwood can provide sustainable energy in the future for Pakistan's households. However, in order to have such a situation, a number of steps have to be undertaken: (i) transition from reliance on old-growth trees to farm trees, deliberately planted and managed on private farmlands, to meet major fuelwood requirements; (ii) proper wood-fuel policies and management with focus on supporting people's initiatives at tree planting, interfuel substitution, and fuelwood conservation, without undermining it through subsidies or give-away policies; (iii) stimulating the demand of tim-

ber in the country (75% of any tree ends as waste products usable as firewood) can help in ensuring sustainable fuelwood supplies; and (iv) consistent government pricing policies for household sector fuels (natural gas, kerosene, LPG), increasing availabilities, removal of subsidies, promotion of efficient fuelwood stoves, etc., would rationalize the fuelwood consumption and bring it in balance with the sustainable levels of supply. In addition, the following aspects need to be given serious attention.

1. Governments can normally achieve little, if anything, by trying to intervene in the workings of privately-run fuelwood and timber markets. In Pakistan, there is anyway little need to intervene, because the system of wood trading and transport appears to be working effectively and with good economic efficiency. The large number of traders and the diversity of transport and trading channels ensure a high degree of competition. Most traders are making reasonable, though not excessive, incomes from their businesses. Government policy should be to maintain this private market system with minimum intervention.
2. Land-use alternatives are too important to be dictated by relatively narrow policy objectives such as increased wood production. Farmers should be left free to make educated choices on using their land in the most productive and sustainable way, which would often include a significant emphasis on tree growing. The approach of the government in promoting farmland trees should, therefore, follow a hierarchical structure leading from broad objectives to more specific tree-oriented levels, i.e., first, to devise policies aimed at promoting sustainable land use generally; second, to provide farmers with good and locally relevant information on tree growing as a business enterprise; and, third, to provide incentives for social forestry so long as these do not conflict seriously with other land-use objectives.
3. The quality and extent of information/advice to farmers on growing and marketing trees has an important implication for sustainable fuelwood supplies and production. Some of the major deficiencies are: (i) the management of farm trees; (ii) the manner in which wood is harvested; and (iii) the manner in which the wood markets are operated. Advice through extension services, literature, broadcasts, etc., on these issues should be given a high priority in the development of strategies to promote farm forestry. Information may need to include species choice, management practices such as pruning, thinning, and rotation periods for various products, estimation of tree volumes and weights at the time of sale, and decisions on whether to sell standing trees to a trader or felled trees delivered to buyers. As part of this approach, provincial forestry departments need to monitor the development of expected wood demand from new wood-based industries, including pulp and paper, to ensure that future supply and demand will be at least approximately in balance.
4. Provincial forest departments have been promoting farm forestry through subsidies of various kinds. HESS and other surveys point out that farmers plant trees without the aid of subsidies, in the expectation of making good profits from sales to new wood-based industries. Furthermore, the economic analysis on block plantations versus major agricultural crops shows that subsidies in the first years of plantation establishment make little difference to economic competitiveness, which is dominated by

the price of wood, tree growth rates, and the discount rate employed. Policymakers should, therefore, consider the replacement of subsidies by improved credit facilities for tree growing. Farmers can generally raise loans for agricultural crops, but find it difficult or impossible to raise them for tree crops. Central and provincial governments' forest departments should consider raising this issue with the Agricultural Development Bank and other lending institutions. Improved credit would have a similar incentive, as with subsidies, on tree growing without any charge on public funds.

5. The HESS survey clearly indicates that almost the entire rural population using firewood is 'collecting', and not purchasing. Fuelwood trading is confined primarily to large cities and towns. It is estimated that the autonomous collection of firewood is done from dead branches and discharged cuttings throughout the rural areas; however, country's forest resources and farm trees do not have the capability to generate the dead branches and/or cuttings in the required quantities, and illegal cutting is resorted to meet the firewood needs. The establishment among rural and semi-urban communities of associations for firewood extraction is a critical condition to reducing uncontrolled firewood exploitation. This step requires very careful consideration, as communities should be involved fully in the formation and running of these associations, and the government should only act as a facilitator. These associations should take into account the firewood supply conditions in their particular areas, develop organized extraction programmes, encourage monthly payments (stumpage fee), and organize the collection and use of this fee for creating economic opportunities in their community for women and children, who traditionally collect firewood
6. Federal and provincial governments should facilitate wood-fuel trading by undertaking a countrywide review of taxes on wood transport across divisional/district boundaries, and permits and payments for wood harvesting The purpose of this review should be to remove restrictions on movements (if any), and to simplify and standardize the procedures. The revised tax and permit system should be widely publicized, for example, at all transport check points. The present tax system is onerous and reduces incentives for tree growing and effective marketing. It is grossly inconsistent and poorly understood, increasing opportunities for abuse and damaging exploitation of wood producers and traders.

Commercial fuels infrastructure and inter-fuel substitution

Given the current gas and electric pricing for the household sector, which is lower than the true economic cost, accelerating the rate of gas and electric connections will have high net economic costs, but will provide households with a higher level of welfare in non-monetary terms. The only way to determine whether this welfare gain is worth the economic cost is to set prices to the economic cost of the fuel, and let households decide for themselves Therefore, connection rates should be accelerated only if households are paying the full economic cost. However, even with this qualification, steps should be undertaken to enable the expansion of electricity and natural gas networks to meet long-term demands. One approach to manage electricity demand is to combine policies for economic pricing and improved efficiency. This would, by 2008, reduce the electricity consumption to

22.7 TWh from the 34.5 TWh estimated under the baseline scenario. Although this is still a 229% increase over the 1991 consumption of 9.9 TWh, it is far less than the 348% increase of the baseline scenario. This approach may, in fact, be a matter of necessity, if Pakistan's chronic power scarcity persists. Similar policies should be adopted for natural gas supplies. However, whatever policies are adopted, the magnitude of transmission and infrastructure development work should be evaluated, and concerted efforts and budgetary allocations must-made to realize the targets.

By 2008, the total LPG consumption increases nearly five-fold under the baseline scenario. The importance of planning for LPG supply infrastructure, therefore, should not be overlooked. In the light of the government's commitment to privatization, the private sector should be given a major role in the expansion of LPG supply network. Investments will be required for: (i) port facilities to handle unloading/storage of large shipments by sea, to take advantage of economies of scale; (ii) trucks for transporting LPG from port storage to bottling plants; (iii) bottling plants; and (iv) LPG bottles. In addition, the government should ensure that safety regulations are in place and are strictly enforced.

The transport of purchased firewood in the urban centres of Pakistan typically involves high tonnages over large distances by six-wheel Bedford trucks. Not surprisingly, transport costs are the largest component of the wood purchase prices, accounting for 67% of *en route* and yard arrival costs. A variety of animal-driven or tractor trolleys are also used for hauling farmwood to the traders. Costs are the lowest for roadside traders in Punjab and NWFP, who operate close to farm supplies. Any government intervention in the pricing of diesel oil is bound to have a major (and undesirable) impact on fuelwood prices. The government may facilitate the utilization of large-tonnage fuel-efficient trucks and simplify procedures for fuelwood movements, so that traders do their business according to the market conditions.

Institutional development

It is important to recognize the importance of the household sector in the overall energy consumption in the country. Within the overall mix, the dominant position of biomass fuels also calls for designating an institution for the long-term development planning of the household sector. It is felt that Planning Division (Energy Wing) should fill this role, and a specialized cell created for this purpose. This cell should have a multi-disciplinary team of planners; however, due to its very nature, it will have to develop formal links with a number of other institutions in the country, like the utilities and energy organizations, statistical bureaus, forest institutes, etc.

HESS and other related surveys have provided a basis for creating a comprehensive database on household consumption, biomass resources, and annual sustainable productivities. However, all these surveys were snapshots for a single year, and can say little about the changes which may be occurring over time. Similarly, fuelwood supplies from farmlands can be affected by crucial factors such as planting and felling trees, establishment of boundary trees versus block plantations, or farmers' attitudes to trees versus other agricultural activities. It is, therefore, important to establish regular surveys to collect key data on household consumptions and biomass supplies (tree plantation, management, production, costs, revenues, prices, etc.), on a consistent format for comparability of results.

It is felt that designated national institutions should be involved as a project team to utilize their specialized strengths, share databases, and undertake analytical work on a continuous basis.

Conclusions

The importance of biomass fuels in the overall energy mix, particularly for the household sector has been clearly manifested. It is also evident that this importance is likely to continue in future on account of rapid population growth, and increasing consumption levels, regardless of aggressive electrification or gas distribution policies. It is, therefore, of utmost importance to formulate and implement a medium- and long-term household energy strategy, which could help avoid undesirable consequences of a mismatch between the sustainable productivity of biomass resources and the actual consumption. Such a strategy inevitably has to be multi-pronged; it has to address the larger issues of demand management; present policy measures for enhancing sustainable fuelwood production; and provide guidelines for the development of infrastructure of modern fuels. The household energy strategy needs to be properly institutionalized in the overall planning framework of the country, and needs to be monitored and continually updated, for which clear responsibilities have to be assigned. The structure of the household sector in many South-East Asian Association for Regional Cooperation (SAARC) countries is similar to that of Pakistan, and it is anticipated that the broad principles could be equally applicable in these countries in the formulation of such a strategy.

References

GOP 1993. Household Energy Policy Analysis in Pakistan. Final Report (May 1993). Islamabad: Government of Pakistan.

UNDP/GOP. 1991. The Household Energy Strategy Study Project. Islamabad. United Nations Development Programme/Government of Pakistan.

MULTI-PURPOSE TREE SPECIES FOR BIOENERGY PRODUCTION

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Introduction

The natural forests in the tropics are disappearing at a very fast rate, at 15.4 million hectares (mha) per year, for meeting the demand of wood for various purposes (Lanly 1982). The situation is more alarming when one considers the annual total consumption of fuelwood (1.38 billion cubic metres) in the developing countries. Fuelwood extraction is one of the major reasons for the depletion of forests (World Bank 1979). However, fuelwood requirement is continuously increasing, and it has been predicted that about 3 billion people in developing countries will experience fuelwood scarcity by the year 2000 (FAO 1983; UN 1984). The increasing requirement of lands for agriculture is perpetually competing with the sustainability of forests. Hence, the imperative need is to not only revegetate the millions of hectares of wastelands in the country (Hegde, Abhyankar 1986), but also to assess the biomass productivity of fast-growing multi-purpose tree species which may be raised on marginal lands. Biomass production and productivity improvement programmes generally include two steps: species selection and cultural techniques (du Cross 1986). The paper describes the results of growth, biomass production, nutrient content, and photosynthetic characteristics of selected multi-purpose tree species (MPTS) in a semi-arid region

Materials and methods

Site

The study was conducted at Madurai, Tamil Nadu. The average mean ambient temperature at site ranges between 25.3 and 31.5 °C. The average daily temperature is 21.7 °C in December and 38.2 °C in April–May. The mean annual rainfall of the area is 842 mm, of which 48.6% is received during the north-east monsoon (October–December), 37.8% during the south-west monsoon (June to September), 9.7% during summer (March–May), and 3.9% during the winter. The temperature regime of the area is isohyperthermic, and the soil moisture regime ustic. The soils of the site are fine loamy, mixed isohyperthermic, and typical haplustalf but deep, well-drained, alkaline (pH 8.2), and poor in nitrogen, phosphorus, and organic matter.

Plantation

Planting stock for this experiment comprised six-month old seedlings of *Acacia nilotica* (L.) Wild ex Del., *Albizzia lebbeck* (L.) Benth, *Dalbergia sissoo* Roxb., and *Eucalyptus camaldulensis* Dehnh. Seeds of *A. nilotica* and *A. lebbeck* were pretreated in water at 100 °C for 30 seconds, followed by soaking for 24 hours in water at room temperature. The swollen seeds, thus obtained, were inoculated with palletted rhizobium, and sown in polythene bags (20 × 15 cm) containing a mixture of clay, sand, and farmyard manure in the ratio of 5:4:1. The pods of *D. sissoo* were soaked for 24 hours in water at room temperature, and after inoculating with palletted rhizobium, were sown in polythene bags. Seeds of *E. camaldulensis* were sown directly in the mother beds, and seedlings with two to four true leaves were transplanted to polythene bags. Seedlings were grown in tree shade for the first two months, and subsequently exposed to full sunlight.

Plantation plots were established in 1989 with a stocking of 720 trees per hectare. A total of 180 plants of each of the species mentioned earlier were planted in six replicates. The treatments were in randomized complete blocks of four species. The site was cleared with disc harrow just prior to plantation. Seedlings were transplanted into pits of 45 × 35 × 45 cm size at spacing of 10 × 1 m.

After two years of planting, their height and diameter at breast height (dbh) were measured. Trees were divided into four diameter classes and four sample trees were selected at random for each species treatment for biomass estimation. The biomass yields, both below-ground as well as above-ground, were estimated component-wise (Ovington, Forest, Armstrong 1967). Samples of each biomass component were dried at 110 °C and reweighed, the resultant of dry/fresh weight ratios were used to convert fresh weight biomass to their oven-dry equivalent. Nutrient analyses were carried out in air-dried (70 °C) samples analysis

Further, 0–15 cm depth soil samples were collected from each species plot, oven-dried at 105 °C for overnight, and were analysed in terms of change in soil pH and mineral contents. The soil pH was measured in a 1:2.5 mixture of soil: de-ionized water using a Corning pH meter. The soil samples were ignited at 475 °C; available N and P were determined from sulphuric acid, Kjeldahl digest (Bremmer 1965) using an automated colorimetric technique and total K was determined by the hydrofluoric dissolution–atomic absorption analysis (Desjardins 1978).

Air-dried samples of each biomass component were ground in a willy mill. Ground samples were ashed at 450 °C in a muffle furnace for four hours, and the ash digested with sulphuric acid to determine total N and P in Kjeldahl digest (Bremmer 1965) with the help of an automated calorimetric technique, and total K was determined by hydrofluoric dissolution and atomic absorption spectrophotometry (Desjardins 1978).

Finally, the chlorophyll contents on a fresh weight basis were arrived at by a colorimetric technique in plant samples collected from the same trees used for gas-exchange. The photosynthetic rate and stomatal conductance were measured by a Li-Cor-6000 portable photosynthetic system (Li-Cor Inc. Lincoln, NE 68504).

Results and discussion

Growth performance

The mean height of plants varied considerably between species after 24 months of planting (Table 1). *E. camaldulensis* attained the maximum mean height (5.84 m) followed by *Albizzia lebbeck* (4.67 m) and *D. sissoo* (4.60 m). *A. nilotica* recorded the minimum height growth (4.04 m). An important parameter for estimating the fuelwood potential for multipurpose tree species, diameter at breast height (dph) varied considerably among different species and *E. camaldulensis* recorded the maximum dbh (6.20 cm) followed by *A. lebbeck* (4.90 cm). Dbh growth was almost comparable in *D. sissoo* (3.62 cm) and *A. nilotica* (3.60 cm). The growth trends observed are near similar to the results reported for similar plantations managed at 10–15 year rotation in India and also in Indonesia (Parrotta 1987; Webb, Wood, Smith 1980; Venkataramani 1968).

Biomass productivity

D. sissoo recorded the highest mean root biomass [1.39 kg d. w. (dry weight)/tree] followed by *A. nilotica* (1.28 kg d. w./tree). *A. lebbeck* recorded the lowest mean root biomass (0.52 kg d. w./tree) (Table 1). *E. camaldulensis* ranked first in producing mean bole biomass (4.09 kg d. w./tree) followed by *D. sissoo* (3.39 kg d. w./tree). *A. nilotica*

Table 1
Mean height, dbh and biomass yield of four multi-purpose tree species at 24 months after planting in semi-arid region

Species	Growth[a]		Mean biomass yield (kg dry weight/tree)[b]				
	Mean height (m)	Mean dbh (cm)	Root	Bole	Branch	Leaves	Total
A. nilotica	4.04	3.60	1.28	2.26	2.44	0.56	6.54
A. lebbeck	4.67	4.90	0.52	2.32	0.72	0.32	3.88
D. sissoo	4.60	3.62	1.39	3 39	1.89	0.62	7.29
E. camaldulensis	5.84	6.20	1.12	4.09	1.16	0.93	7.30

[a]mean of 180 trees; [b]mean of four sample trees from each species plot.

and *A. lebbeck* produced a comparable bole biomass, with values of 2.26 and 2.32 kg d. w./ tree respectively. A comparison of mean branch biomass yield revealed that *A. nilotica* produced the maximum (2.44 kg d. w./tree) followed by *D. sissoo* (1.89 kg d. w./tree). The branch biomass was found to be the lowest in *A. lebbeck* (0.72 kg d. w./tree). The mean leaf biomass was the highest in *E. camaldulensis* (0.93 kg d. w./tree). *D. sissoo* and *A. nilotica* produced a comparable leaf biomass, the values being 0.56 and 0.62 kg d. w./tree, respectively. *A. lebbeck* recorded the lowest leaf biomass (0.32 kg d. w./tree).

A comparison of mean total biomass yield in different species revealed that both *E. camaldulensis* and *D. sissoo* produced higher total biomass yield (7.30 kg d. w./tree) followed by *A. nilotica* (6.54 kg d. w./tree). *A. lebbeck* recorded the lowest total biomass yield (3.88 kg d. w./tree). Although *D. sissoo* showed lesser growth in terms of height and dbh as compared to *E. camaldulensis*, yet it managed to produce a total biomass yield (7.29 kg d. w./tree) comparable to *E. camaldulensis* (7.30 kg d. w./tree) due to its higher quantity of root and branch biomass. Similarly, *A. nilotica* recorded lesser height and dbh growth than *A. lebbeck*, but produced significantly higher total biomass (6.54 kg d. w./ tree) than the latter (3.88 kg d. w./tree) due to production of larger photosynthate in the form of roots, branches, and leaves (Table 1) The results indicate that species vary in terms of growth and biomass production, and *E. camaldulensis* and *D. sissoo* yielded significantly higher biomass during the 24th month. The results corroborate with the findings of Hall (1979) who has suggested that for perennial crops, biomass production depends upon the species habit and cultural treatments. The higher plant productivity in the present case may be due to the availability of more nutrients and solar energy under wider spacing, which suggests that plants behave differently when alone or in a group with regard to the strategy of dry matter production (Larcher 1975).

Soil properties

Analysis of nutrients and pH in soils collected in different species treatments revealed that there is a marked difference in soil characteristics except soil pH, in the soil prior to planting, and soil data from the same plot 24 months later (Table 2). Soil nutrients showed a significant increment at 24 months after planting, and varied between species plot. Avail-

TABLE 2
Soil pH and mineral content (ppm) in surface soil (0–15 cm) initially and at 24 months after planting of four multipurpose tree species[a]

Species	pH	N	P	K
A. nilotica	8.1	159	011	527
A. lebbeck	8.1	188	012	397
D. sissoo	8.0	213	025	355
E. camaldulensis	8.2	169	021	462
Initial[b]	8.2	113	010	350

[a]averaged for all plots in study; [b]based on six plots in each species treatment.

able N content was the maximum in *D. sissoo* (213 ppm) followed by *A. lebbeck* (188 ppm). Such increase in nitrogen content may be attributed to the addition of N-rich litter produced by *D. sissoo* and *A. lebbeck*. Phosphorus content also recorded the highest value in *D. sissoo* (25 ppm) followed by *E. camaldulensis* (21 ppm). The higher levels of phosphorus in *D. sissoo* may also be due to its ability to fix nitrogen as legumes in general have high P requirement for growth and nitrogen fixation (Edwards 1977). However, the increase in the level of phosphorus in *Eucalyptus* may be attributed to its capacity to utilize the soil phosphorus complex generally regarded insoluble and unavailable (Mullette, Hannon, Elliott 1974). K content was recorded higher for *A. nilotica* (527 ppm) followed by *E. camaldulensis* (462 ppm), and *A. lebbeck* (397 ppm). The present increase in K content is not surprising as it is associated with both nutrient cycling and mining of the minerals from the lower zones (Mathur, Kimothin, Gurumurthi 1984). In general, the soil nutrient contents were at, or above, the critical levels after two years of planting, and are similar to the results reported by Montagnini, Sancho (1990). The results also indicate that there is a significant built-up of nutrients in the soil at 24 months after planting in all species in general and *D. sissoo* in particular, which may be a result of a large root growth which is evident from the production of higher root biomass in *D. sissoo* (Table 1). Root activity and rooting depth is the main factor by which trees alter the fertility of the soil by taking up nutrients found in low concentration. These nutrients ultimately become concentrated at the soil surface through the litter-fall and decomposition (Virginia 1986). A significant accumulation of the macronutrients has been measured in the surface soil beneath *Prosopis* canopies in natural systems (Barth, Klemmedson 1978; Tiedemann, Klemmedson 1973; Virginia, Jarrell 1983).

Plant nutrient content

The species treatments considerably affected the concentration of plant nutrients (Table 3). N content was found to be maximum in *D. sissoo,* followed by *A. lebbeck* and *E. camaldulensis* whereas *A. nilotica* showed the lowest level. The leaves recorded the maximum N content followed by the roots. However, the bole and branch were comparable in N levels. Although the phosphorus content did not show any considerable variation between species, different plant components showed variation in phosphorus like the N content. *D. sissoo* recorded the maximum K content followed by *A. lebbeck*, while *E. camaldulensis* and *A. nilotica* showed the lower levels. Leaves contained higher K, followed by the roots. The results reveal that the nutrient levels varied between species and *D sissoo* recorded considerably higher nutrient level than the rest Such a situation may be attributed to its enhanced root proliferation (Table 1) with consequent better exploitation of soil nutrients. Requirements of nutrients by different species vary and also vary with age and component development (Young, Carpentor 1967). The data also indicate that the largest concentration of nutrient elements was in the leaves of all the species studied with much lower levels in the stems, with intermediate levels in roots. The results corroborate with the observations made for different temperate and tropical tree species by Jorgensen, Wells (1986); Maghembe, Kariuki, Haller (1983), Wittwer, Immel (1980); Rodin, Bazilevich (1967).

TABLE 3
Plant nutrient content (ppm)[a] of four multi-purpose tree species in different plant components at 24 months of planting

Species	Root	Bole	Branch	Leaf
A. nilotica				
N	540	492	651	969
P	041	027	036	042
K	182	280	210	545
D. sissoo				
N	1329	1313	970	2356
P	034	028	049	039
K	428	489	417	888
A. lebbeck				
N	780	570	558	1338
P	038	040	039	041
K	345	277	469	601
E. camaldulensis				
N	796	448	448	1017
P	033	026	034	044
K	404	164	224	355

[a]based on four trees in each species treatment.

Photosynthesis

A comparison of results presented in Table 4 shows that *A. nilotica* recorded higher chlorophyll content followed by *A. lebbeck*; it was the lowest in *E. camaldulensis* Chlorophyll a/b (chl a/b) ratio did not vary between species except in *A. nilotica* where it recorded slightly higher value than the rest. *A. nilotica* recorded considerably higher photosynthetic rate (6.59 μmol m^{-2} s^{-1}) followed by *A. lebbeck* (3.80 μmol m^{-2} s^{-1}), *E. camaldulensis* (3.72 μmol m^{-2} s^{-1}); and *D. sissoo* (2.23 μmol m^{-2} s^{-1}) in diminishing order which is in conformity with the study reported earlier (Larcher 1969; Schulze, Glatzel, Turnen 1984). The stomatal conductance also showed a trend similar to photosynthesis in different species treatments. The values reported for stomatal conductance for different species are in agreement with the results of Schulze, Glatzel, Turnen (1984); and Marek *et al.* (1989). The study brings out a significant correlation ($r > 0.86$ for all the species) between rate of photosynthesis and stomatal conductance and a positive correlation between photosynthetic rate and stomatal conductance as described for forest tree species by Marek *et al.* (1989). Although *A. nilotica* showed considerably higher rate of photosynthesis than the rest, the mean total biomass production was found higher in *D. sissoo* and *E. camaldulensis* than *A. nilotica*. The higher rate of photosynthesis in *A. nilotica* may be attributed to its higher chlorophyll (chl) content (Table 4) which suggests that photosynthetic productivity, determined by leaf-activated radiation condition and species, are different in controlling the net photosynthetic rate (Marek *et al.* 1989). No distinct correlation between photosynthesis and biomass production was noticed, which is contrary to the report of

TABLE 4
Chl content, photosynthetic rate, and stomatal conductance of four multi-purpose tree species at 24 months after planting in the field[a]

Species	Chl a (mg gfw $^{-1}$)	Chl b (mg gfw^{-1})	Total chl (mg gfw^{-1})	Chl a/b	Photo-synthetic rate (μmol m^{-2}s^{-1})	Stomatal conductance (μmol^{-2}s^{-n1})
A. nilotica	1.79	1.57	3.36	1.14	6.59	257
A. lebbeck	1.33	1.24	2.57	1.07	3.80	134
D. sissoo	0.69	0.64	1.33	1.08	2.23	158
E. camaldulensis	0.49	0.45	0.94	1.08	3.72	170

[a]Averaged for all six plots.

Wilhelm, Nelson (1979) who showed that the rate of photosynthesis is directly proportional to the concentration of water soluble carbohydrates. However, the present results are similar to the findings of Heichel, Musgrave (1969) and Rhodes (1972) that correlation between the rate of net photosynthesis per unit leaf area and biomass production are generally poor.

The results suggest that there is enormous scope to use MPTS for raising fuelwood plantations on marginal lands, not only for fuelwood production, but also for improving the soil condition Bioenergy plantations of *D. sissoo, E. camaldulensis*, and *A. nilotica* are expected to be effective for the semi-arid regions.

References

Barth R C, Klemmedson J O 1978 Shrub-induced spatial patterns of dry matter, nitrogen, and organic carbon. *Soil Science Society Am. Journal* 42· 804–809.

Bremmer J N, 1965 Total nitrogen. In methods of soil analysis. Part 2. Chemical and microbial processes. *Agronomy* 9· 1149–1178.

Desjardins J G 1978. Determination of total major and minor elements. *In* McKeague J A (ed) *Manual on Soil Sampling and Methods of Analysis*. Ottawa. Subcommittee on Soil Analysis, Canada Soil Survey Committee, Research Branch.

du Cross E T 1986. Production of biomass and improvement of productivity in forest trees. *In* Grassi G, Zibbetta H (eds) *Energy from Biomass*. I Proceedings of the Forest Contractor's Meeting, London/New York: Elsevier Applied Science.

Edwards D G. 1977. Nutritional factors limiting nitrogen fixed by rhizobia pp. 189–204 *In* Ayanaba A, Dart P J (eds). *Biological Nitrogen Fixation in Farming Systems of the Tropics* New York. Wiley.

FAO 1983 *Fuel Wood Supplies in Different Countries*. Rome: Food and Agriculture Organization

Hall O D. 1979. Biological solar energy conversion for fuels. *Nature* 278 114–117

Hegde N G, Abhyankar M L 1986. *The Greening of Wastelands* Pune Bhartiya Agro Industries Foundation.

Heichel G H, Musgrave R B. 1969. Varietal differences in net photosynthesis of *Zea mays* L *Crop. Science* 9 483–951.

Jorgensen J R, Wells C G 1986. Tree nutrition and fast growing plantations in developing countries. *International Tree Crops Journal* 3. 225–244

Lanly J P. 1982. Tropical Forests Resources. *FAO Forestry Paper* 30 Rome: Food and Agriculture Organization.

Larcher W. 1969. The effect of environment and physiological variables on the growth and on the carbon dioxide gas exchange of trees. *Photosynthetica*. 3· 167–178.

Larcher W. 1975 *Physiological Plant Ecology* Berlin/Hiedlberg/New York· Springer Verlag

Maghembe J A, Kariuki E M, Haller R D 1983 Biomass and nutrient accumulation in young *Prosopis juliflora* at Mombasa, Kenya *Agroforestry Systems* 1. 313–321.

Marek M, Masarovicova E, Kratockvilova I, Elias P, Janous D. 1989 Stand microclimate and physiological activity of tree leaves in an oak-hornbeen forest. II. Leaf photosynthetic activity *Tree* 4· 234–240

Mathur R S, Kimothi M M, Gurumurti K. 1984. Quest for improving the production and availability of forest biomass – a review *Indian Forester* 110(8) 695–725.

Montagnini F, Sancho F 1990 Impacts of native trees on tropical soils. A study in the Atlantic lowlands of Costa Rica. *Ambio* 19(8). 386–390

Mullette K J, Hannon N J, Elliott A G L. 1974 Insoluble phosphorous usages by *Eucalyptus Plant and Soil* 41. 199–205.

Ovington J D, Forest W G, Armstrong J S 1967 Tree biomass estimation. pp 4–31 Symp Pri Production and Mineral Cycle in the Natural Ecosystem AAAS Ecological Society of America

Parrotta J A. 1987 *Albizzia lebbeck* (L) Benth. Silvics of Forest Trees of American Tropics. SOITF-SM7. New Orleans, LA: US Dept. of Agricultural Forestry Service Institute of Tropical Forestry South Forestry Experimental Station.

Rhodes I 1972 Yield leaf area index and photosynthetic rate in semi-perennial ryegrass (*Lolium perenne* L.) selections *Agriculture Science* 78· 509–511

Rodin L E, Bazilevich N I. 1967. *Production and mineral cycling in terrestrial vegetation*. Fogg G E (ed). Edinburgh/London: Oliver and Boyd. 288 pp.

Schulze E D, Glatzel G, Turnen 1984 Carbon, water and nutrient relations of two mistletoes and their hosts – a hypothesis. *Plant Cell Environment* 7 293–299.

Tiedemann A R, Klemmedson J O. 1993. Effect of mesquite on physical and chemical properties of soil *Journal Range Manage* 26: 27–29

UN. 1984 *United Nations Energy Statistics Year Book* New York. United Nations. 254 pp.

Venkataramani P. 1968 Silviculture of the genus *Albizzia* and its species. *Silviculture of Indian Trees No 22* New Delhi· Government of India. 54 pp.

Virginia R A. 1986. Soil development under legume tree canopies *Forest Ecology and Management*. 16. 69–79

Virginia R A, Jarrell W M 1983 Soil properties in a mesquite-dominated Sonoran Desert ecosystem *Soil Science Society Am. Journal* 47· 138–144.

Webb O B, Wood P J, Smith J. 1980. A guide to species selection for tropical and subtropical plantations Tropical Forestry Paper No. 15. London· Commonwealth Forestry Institute, Department of Forestry, University of Oxford/Overseas Development Administration. 256 pp

Wilhelm W W, Nelson C J 1979 Growth analysis of tall fescue genotypes differing in yield and leaf photosynthesis *Crop Science* 18: 951–954

Wittwer R, Immel M 1980 Chemical composition of five deciduous tree species in four years old closely spaced plantations. *Plant and Soil* 54: 461–467.

World Bank. 1979. *Prospects for Traditional and Non-conventional Energy Sources in Developing Countries.* Washington, DC: World Bank. 132 pp

Young H E, Carpentor P N. 1967. Weight, nutrient element and productivity studies of seedlings and saplings of eight tree species in Maine. *Technical Bulletin 28.* Oronto, Maine· Agriculture Experimental Station.

JOINT FOREST MANAGEMENT: INSTITUTIONAL INITIATIVES TOWARDS BIOMASS ENHANCEMENT

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Introduction

Forests constitute a very important renewable natural resource, and play a key role in the socio-economic development of nations, specially the developing ones, through the utilization of goods and services that the forests provide. These are remarkably efficient biological systems, which often attain high levels of organic production at sites regarded as too poor for agriculture, besides holding value for a number of economic and social uses. Forests are relatively long-lived, dynamic, and resilient ecosystems, which can withstand a certain degree of perturbation and manipulation, constitute a source of diverse habitat for a wide variety of flora and fauna, and serve as rich reservoirs of biological diversity and genetic variability. The critical role of forests in matters of conservation and enhancing the quality of environment, regulation of water regimes and protection of watersheds, combating desertification, and maintenance of ecological balance, recreation, and wildlife are well known. Paradoxically, however, human beings are trying to restrict such efficient biological systems mainly because of competing agriculture, subsistence living, and developmental needs of a rapidly growing population, when consideration needs to be given to increasing the area under such ecosystems towards the wider national interests of ecological stability, environmental security, conservation of biological diversity, and poverty alleviation.

The reduction in the global forest cover hindered human progress little, if at all, for centuries. In fact, clearing of forests for food production and harvesting of forest products were rather pivotal to economic and social development. However, the reckless loss of tree

cover in the recent past has already begun to impinge directly on the ecological stability, biological diversity, economic viability, food security, and environmental safety of a number of nations, mostly in the developing world. The denudation of forests, with the inevitable consequences of soil erosion and run-off, has rendered once luxuriantly clad watersheds almost bare in many regions. While forests continue to deteriorate under the stresses of air pollution and acid rain in the industrialized nations, degraded Himalayan watersheds contributed to the worst downstream flooding, on record, in 1987 and 1988 (Brown, Flaven, Postal 1989; Rangachari 1993; Verghese *et al.* 1994). The ravages of recurrent and widespread floods are a result of the natural control mechanism of water retention and gradual release having been disrupted by surface erosion and rapid run-off Shortages of food, fuel, timber, fodder, water, and other resources are symptomatic of environmental deterioration.

The crucial role played by forests and soils in the global carbon cycle has been brought into focus by the climatic changes induced by CO_2 and other greenhouse gases. It is reported that, in 1988, deforestation probably released one-fifth to half of as much carbon as the burning of fossil fuels (Brown, Flavin, Postal 1989).

Global forests

Though few nations have taken inventories of their forests, the best estimate is that just about 24% [1.5 billion hectare (bha)] of undisturbed primary forest remains of the 6.2 bha that existed before the beginning of settled agriculture (Postal, Ryan 1991) While forest cover in most of the industrialized countries is fairly stable, the most worrisome feature of the world's forests is that, in most tropical countries, forests are being cleared or degraded at a rapid rate mainly to satisfy the basic subsistence needs of the rural poor. This tropical deforestation has caused serious environmental, economic, and social repercussions with disastrous consequences, though its extent remains uncertain

Tropical forest resources

Developing countries contain virtually all the forests of the tropics, which account for nearly half of the world forest resources but provide less than half of the global output of wood and only about one-fifth of the total output for industrial purposes. Of the 1400 million cubic metres (mm^3) of wood removed annually from tropical forests, little less than 1200 mm^3 is used as fuelwood and the balance for purposes other than fuel (FAO 1986) More than half of the world's tropical forests have disappeared since the turn of the century, and, globally, over 11 million hectares (mha) are destroyed annually (Murray 1990) More recent studies have, however, shown that up to 20.4 mha of tropical forests are being lost every year (79% over 1980 estimates) and this additional yearly forest loss represents the size of Panama (WRI 1990). Latest figures released by FAO (FAO 1990, TFAP 1990) indicate that annual deforestation in the tropics (62 tropical countries) has increased from 11 3 to 17 mha from 1980 to 1990.

Indian resource base

The status of forests in the Indian subcontinent, much of which was in a large part densely forested even in recent historical times, has been conditioned by vegetational and geologi-

cal evolutionary history, latitude, altitude, and aspects which affect the general and local soil conditions, drainage patterns, and macro- and micro-climatic features. Over time, this pattern has, in turn, been very significantly modified by anthropogenic activities which have left indelible marks and scars on the environment and landscape.

Out of a total geographical area of 328.726 mha, about 76.77 mha constituting 23.35% of the total land area of India is recorded/classified as forest with or without any tree growth (FSI 1995); forestry as a major land use is next only to agriculture. This extent of forest area does not reveal the actual position as the figures indicate, in as much as the assessment made by the Forest Survey of India (FSI) in 1993, based on satellite data, places the *actual forest cover* in the country at 64.6 mha or 19.47% of the total geographical area. Of the total actual forest cover, 38.6 mha (11.73%) constitute dense forest cover (crown density 40% and above), 25 mha (7.61%) as open forest cover (crown density 10% to less than 40%), and 0.13% (0.43 mha) as mangroves. The average per capita forest area is 0.09 and 0.08 ha for the recorded and actual forest cover, respectively, though these figures vary with different states; Arunachal Pradesh has the highest per capita forest area (7.94 ha).

The forest area lost for various purposes during the period 1952 to mid-1993 is inferred to be nearly 4.6 mha, with 0.12 mha having been lost annually, on an average. The impact of agriculture on the denudation of forests has been the maximum as exemplified by the diversion of a large forest area (2.62 mha) to agriculture between 1952 and 1980 (MoEF 1987). In fact, agriculture has always expanded at the expense of forests and large areas have been cleared in the past and released for agriculture. It is reported that nearly 0.7 mha of forest land was encroached upon between 1951 and 1982 (MoEF 1987). The total forest area affected by shifting cultivation stands at 5 mha with an annual area of 1 mha under this practice, which implies a disturbing shortening of the *Jhum* (crop-fallow) cycle to five years.

Changing concerns

There has, however, been a profound change in the understanding of, and concern about, the forests of the developing world. It is now amply clear that forests play an even more important role in the economic, social, ecological, and environmental health of nations than had been recognized earlier. They also have a *vital* role in mitigating the impact of the energy crisis, rural development, and increasing agricultural production. The importance of various forest products, specially the non-timber forest products (NTFP), in providing employment, incomes, and sustenance to people living in and around forests and the rural poor, is now better appreciated In fact, forests are a vital component of the survival economy of these underprivileged communities. The significance of forest ecosystems in maintaining biological diversity (specially tropical forests), and their crucial role in the carbon cycle and global climate change, are now better recognized than ever before.

These new and emerging priority areas of concern call for a rethinking and reorientation in forest management policies and development programmes, both with regard to the crucial role that forests play in ecological/environmental security and maintenance of biological diversity and in increasing the forest resource base and its productivity Equally important and absolutely essential is the effective involvement and participation of the

local communities (including women) in establishing sustainable natural resource management systems.

Why joint forest management?

India's human population has risen from 361 to 880 million between 1951 and 1994, and its livestock population from 292 to 450 million in the same period. This reflects the quantum of biomass that is being consumed. As the major consumption of forest products take place through informal non-market mechanisms, reliable figures of forest biomass removals and supplies are not available. Table 1, however, indicates some estimates in this regard pertaining to the year 1985/87.

The total annual increment of Indian forests is 87.6 m^3 (1.14 m^3/ha, taking recorded forest area into consideration), which is one of the lowest against the world average of 2.1 m^3/ha. More than half of the energy requirement of the country is met from the forests in the form of biofuels. In the process, about 235 mm^3 of firewood is removed from the forests, while the sustainably extractable quantity is only 40 mm^3. Thus, all extractions above the annual increment have contributed to the degradation of the growing stock. Industrial wood consumption is over 27 mm^3 per annum, against a production of just 12 mm^3 Our livestock requires 980 million tonnes (mt) of green, and 780 mt of dry fodder annually; while only 250 mt of green and 414 mt of dry fodder can be extracted sustainably from the existing resources. It is obvious that the remaining supply comes from the deforestation and degradation of the growing stock beyond its regenerative capacity.

The increasing depletion of India's forest wealth has brought into sharp focus the inherent inadequacy of the traditional systems of forest management in sustaining the forest resource base against the mounting human and livestock population pressures, industrialization, urbanization, and overall economic development. The widening demand–supply gap of biomass for energy, fodder, timber, and as pulpable raw material is creating an unprecedented imbalance to find the forests and foresters alike ill-prepared to fulfil these demands. It is now widely accepted that unless local communities (including women) are effectively involved in establishing sustainable resource management systems, deforestation will continue at a rapid rate much to the detriment of the country's ecological stability, economic viability, conservation of biological diversity, environmental security, and

TABLE 1
Forest biomass: consumption and supply

Biomass	Consumption	Supply	Deficit
Fuelwood (mm^3)[a]	235	40	195
Green fodder (mt)[b]	932	250	682
Dry fodder (mt)[b]	780	440	340
Industrial wood (mm^3)[a]	27	12	15

[a]MoEF (1987); [b]NWDB (1988).

biomass productivity with disastrous consequences. Involvement of user communities is thus imperative to the problems of deforestation and land degradation in India.

The limitations of the traditional approach have led to the exploration of several alternative systems involving meaningful participation of forest-dependent rural communities in managing natural resources. Private and community efforts have a considerable role in the sustainable management of forests and striking successes have been achieved. Several models of participatory resource development in Haryana, Gujarat, West Bengal, Madhya Pradesh, and Orissa provide successful examples of community management wherein user community-based institutions are involved in the protection, management, and development of forest resources.

Evolution of joint forest management

Participatory action involving the Forest Department (FD) and local communities, for the regeneration of degraded forests through effective protection, was started as a pilot project at Arabari, West Bengal, in 1971/72 This cooperative action was a response to the situation in which the closure of areas by villagers living on the fringe of the forest, to grazing and cutting, resulted in their rapid regeneration. Based on the Arabari experience, more than 1250 village forest protection committees, covering an area of 152 000 ha of degraded forests, were formed during the next eight years in West Bengal (Ford Foundation 1991) Today, over 2090 rural communities in the state are participating with the government to manage over 300 000 ha of natural sal forests (Bardhan Roy 1993).

The Arabari experience was followed, in the mid-70s and the early 80s by the Sukhomajri experiment (outer Shivaliks) with the active participation of the Haryana FD (HFD) and the local communities. The programme was designed to achieve increased productivity and effective resource conservation. The strategy adopted for obtaining the willing cooperation and participation of the local people was to provide irrigation water to the parched agricultural fields by constructing a water-harvesting earth-fill dam in the forest catchment. This strategy captured the attention of the farmers and gave a new direction to the concept of watershed rehabilitation. On the basis of the experience gained, HFD adopted the participatory forest management (PFM) approach for the management of degraded forests in the Shivalik hills in 1989. This produced some positive results in regenerating these forests with attendant environmental benefits

Inspired by the success stories of PFM, the Government of India, on 1 June 1990, issued policy instructions, consistent with the National Forest Policy of 1988, to all state governments, supporting greater participation of village communities and non-governmental organizations (NGOs) in the regeneration, management, and protection of degraded forests. The implications of this document are far-reaching and assertive in the support of PFM strategy. In the last two years, 10 state governments have issued enabling orders/ resolutions to facilitate its implementation.

While nearly 300 000 ha are under joint protection in West Bengal, estimates range from 10 to 25% of all the reserved and protected forests under community protection in Orissa. In the Uttar Pradesh hills, up to 30% of all forest lands are under community man-

agement. More than 25 000 people are engaged in the protection and development of about 15 000 ha of forest under the Joint Forest Management Programme (JFMP) in Haryana. Besides, the programmes of state FDs (SFDs), user communities are collaborating with the FDs in Gujarat, Jammu and Kashmir, Tamil Nadu, Karnataka, and Bihar to protect and regenerate degraded forests. One estimate reflects that nearly 3 mha of reserve and protected forests is under JFM (Table 2) (SPWD 1992).

JFM in Haryana

The HFD and the Research Centre of the Central Soil and Water Conservation Research and Training Institute at Chandigarh played a pioneering role in developing an alternative to the existing management systems through their work in the Sukhomajri and Nada villages in late 70s and early 80s. These participatory models emphasized the involvement of forest-dependent rural communities in managing the natural resources in collaboration with HFD. The major lessons that emerged from these models are outlined below.

- A major reason for soil erosion and forest degradation is the unsustainable exploitation of hill resources by the user communities driven by compulsions of subsistence.
- Technical measures of soil and water conservation and afforestation cannot succeed in isolation as the problem lies in the villages and not in the hills.
- Forest–human linkages can be moulded in a manner which balances the twin agenda of sustainable resource development and satisfaction of socio-economic needs.

TABLE 2
JFM national overview

State	Forest protection committees	Approximate area covered (ha)
Andhra Pradesh	260	40000
Bihar	1652	630000
Gujarat	433	65000
Haryana	48	15000
Jammu and Kashmir	617	—
Karnataka	80	—
Madhya Pradesh	4000	105000
Maharashtra	103	—
Meghalaya	—	85800
Orissa	>6000	1518800
Punjab	82	30100
Rajasthan	800	25000
Tripura	56	150000
West Bengal	2423	300000

- The FD and the village communities can be collaborators in developing participatory systems of natural resource management in hilly forest catchments provided they are in the socio-economic interest of all the members of the user community.
- The system of social fencing can be extremely effective in protecting forest areas in comparison to the traditional management practices adopted by the FD

In order to elicit participation and instill a sense of ownership of the forests and their conservation in the village communities, certain site-specific incentives have been provided. These included: (i) irrigation water from soil conservation cum water harvesting structures for enhancing agricultural productivity; (ii) *Bhabbar* (*Eulaliopsis binata* – a fibre grass used in paper and rope making) and fodder grasses by leasing forest areas to village forest management organizations commonly known as hill resource management societies (HRMS) to contribute to economic development; and (iii) bamboos (*Dendrocalamus strictus*) at a concessional rate of Rs 7 for 100 bamboos to *bhanjdas* (basket makers) to provide employment and income. Box 1 provides an overview of the JFMP in Haryana.

Certain strategies have been adopted to sensitize, motivate, and bring about an attitudinal change in the communities and the FD officials, which include:

- meetings, trainings, and workshops for gender sensitization, effective communication, record keeping, process documentation, conflict resolution, micro-level planning, tree plantations, etc.;
- documentation of the process at the village and HFD levels on major decisions, monetary transactions, problem solving, conflict resolution, agreements, etc.;
- women's participation as members of HRMS' and management committees in implementation and managerial roles; and
- research into aspects of success, failure, and sustainability of incentive mechanisms, strategies, benefits, levels of participation, and other issues in order to further the programme.

Box 1

Community forest management systems in (Haryana)

- Forest category: reserve and protected
- Area: 15000 ha (approximately)
- Protection group: HRMS
- Number: 60
- Status: registered bodies
- Membership: male and female from each household and any adult
- Responsibilities: protection; social fencing; micro-planning; grass lease management; plantation in forest
- Protection system: community monitoring; social pressure; sanctions
- Rights: top priority to buy fodder and fibre grass lease; all other NTFP; 25% timber revenue
- Main NTFP: *Bhabbar* grass; bamboo; fodder grass

Impacts of JFMP

An important achievement of JFMP in Haryana has been the involvement of all sections of the user communities, including women, not only in the programme implementation process but also in the crucial decision-making and management processes. This should be seen in the light of the numerous constraints that the process faced, in terms of conflicts both intra- and inter-community, political interference, vested interests of a few attempting individual gains at the society's cost, among other factors. Collective community action and shift to multi-purpose forestry are the new perspectives presented by the programme.

Many a milestone has been reached through this programme; however, in this slow process, certain goals still need to be achieved, like an attitudinal change in the FDs, policy makers, and village communities; greater orientation and awareness; women as equal partners; JFM activities as part of the formal duty structure of the Department; appropriate incentives and award systems for officials working towards the programmes success; resource sustainability; monitoring and evaluation methods, etc. The above are but a glimpse of the range of management, institutional, legal, economic, social, and ecological issues and hurdles that need to be tackled and achieved.

A very important contribution of the research component has been the documentation of the positive and noteworthy impacts of the Programme. A remarkable achievement of JFMP in Haryana is not only the revival of the once degraded hill slopes, increase in biodiversity, and biomass enhancement, but also the development of a viable long-term institutional framework for people's action and cooperation with the FD.

Institution development

The idea of joint management implies the handing over of certain rights to village communities to appropriate natural resources for their own use, while continuing to protect the natural resource base. The afforestation of public/revenue lands through social forestry led to the curbing of customary rights of the poor in these degraded lands for grazing and collection of fuel and fibres (Lele, Mitra, Kaul 1994). Most social forestry schemes were characterized by the lack of a viable long-term institutional framework conducive to the stated objectives of increased biomass for the poor, social equity, and securing legal status for the institution.

Under JFM, the user community is organized into an HRMS, with one man and woman from every family as members and a management committee with at least two women members. Thus, an institutional framework for forest management is provided for, which involves the dependent communities; stipulates well-defined resource characteristics, rules for use and enforcement, and decision-making arrangements governing the relationship between users and regulatory use; and has the backing of the state government orders and the national guidelines supporting JFM. Not only have the objectives of biomass enhancement been achieved, but also issues of equity of access and use have been ensured.

Ecological revival

Increasing protection has positively impacted forest and ecological parameters like tree count, basal area, and regeneration of trees and shrubs (Kaul, Dwivedi, Shah 1995). Tree

population in the protected forests increased from 700 trees/ha in open access areas to 3960 trees/ha. Basal area registered a rise from 6.55 to 21.84 m^2/ha owing to the unhindered growth of trees into higher girth classes. Also consequent was the increased regeneration of commercially important species and a reduction in the low value shrubs and undergrowth. Shrubs decreased from 12 552 to 3264 per ha. A brief of the positive impacts of community participation on forests is presented in Box 2.

Biomass enhancement

Dependence on fodder grass is pronounced owing to the high-yielding milch cattle reared by the villagers. Yields of fodder grass increased from 0.63–0.75 tonnes per hectare (t/ha) under open grazing conditions to 2.80 t/ha with regulated use and protection. *Bhabbar* (*Eulaliopsis binata*) is of commercial importance. While the *Banjara* community makes ropes out of this fibre grass, it also has a large market with the paper mills. The societies have been provided leases for fodder and fibre grasses by HFD. Whereas the fodder grass is harvested by the villagers in a regulated fashion, the fibre grass is managed and sold to paper mills at competitive prices and the profits are put into village infrastructure development. The productivity of this commercial grass has increased from 0.30–0.36 tonnes/ha under over-exploitation to 0.85 tonnes/ha under regulated harvest conditions (Panda *et al.* 1992).

Socio-economic betterment

The different incentives offered under the programme have led to the betterment of the socio-economic conditions of the forest-dependent community. This is important as poverty is a major factor affecting forest rehabilitation.

The supply of irrigation water from water-harvesting structures has led to a manifold increase in agricultural productivity. Increasing yields have also provided for greater agricultural residues, used as fodder supplements. Along with increased fodder grass availability from the forests, villagers have shifted to rearing high-yielding milch cattle in place of low-yielding and grazing livestock.

Box 2

Positive impacts of community management on forests

- Decrease in degradation
- Increase in species composition
- Improved natural regeneration
- Improved stocking density
- Improved ground cover
- Increased yield of commercial and forage grasses
- Drastic reduction in catchment run-off due to improvement in biomass cover
- Decrease in soil pH and electrical conductivity
- Increased organic carbon in soil
- Ecological revival
- Recouping of biodiversity
- Biomass enhancement

Bhanjadas, with an increased bamboo supply at concessional prices, have been able to increase basket production and sales, yielding greater income. This has improved their lot considerably. Apart from individual families, the infrastructure of the villages have also improved with the profits from the fibre grass leases being put to this purpose. Also, the fuelwood required is obtained from the forests in the form of dead and fallen wood, whose availability has also increased owing to the greater number of trees. All this has definitely improved the socio-economic conditions, which, in turn, has helped in improving the health of the forests, and has led to greater biomass production.

Future of JFM

Considering the lesser costs of regenerating forest lands naturally, in comparison to costs for plantation establishment, the potential returns from community-initiated rehabilitation of degraded forests would be significant in terms of:

- rapid increase in the biomass-enhancing supplies of fuelwood and fodder;
- improved vegetative cover with soil and water conservation;
- additional opportunities for socio-economic alleviation through income generation activities linked to protection, planting, harvesting, collection, processing, and marketing of forest produce;
- increased income through high forest productivity; and
- improved resource management.

The new participatory management systems, involving the SFDs and forest communities, make it increasingly evident that without the commitment and cooperation of forest dependants, the forests cannot be saved. The growing body of field evidence and studies indicate the feasibility of the sustainability of the participatory approach. However, institutional reforms, capacity building, responsive management systems, and, above all, an enabling environment will remain a basic requirement towards the stabilization of India's forest ecosystems

The emergence of the larger framework for popular participation is significantly dependent on fulfilment of certain preconditions (Kaul, Dhar 1994).

- Without a serious political commitment, it is virtually impossible to have the meaningful participation of the people in managing and restoring degraded forests In the ultimate analysis, it means devolution of power to the people, which can only come from a strong political faith in their capability.
- The implementing agencies require clear-cut policy guidelines to play a facilitating role. They need clarifications, specially in relation to the objectives of management and their own role Unambiguous legislation and working rules can certainly facilitate this
- Realistic institutional arrangements need to be made for project management. Wherever collective tenure is envisaged for community's participation, local institutional arrangements become crucial for providing a forum for collective assertion of rights,

resolution of internal conflicts, and negation of redundant rules. The more democratic and transparent these institutions become, the greater will be the probability of success.

- Land tenure issues and access rights of the intended beneficiaries need specific attention and resolution. Uncertain tenure and insecurity relating to usage rights dilute commitment on the part of the people.
- Adverse relationship between FDs and the people reflect the historical realities of the past call for reorientation and attitudinal changes not only in the FDs but also in the communities.

The government and the SFDs are encouraging the spread of these promising strategies. Participating communities and FDs must have the commitment and flexibility to work symbiotically in evolving effective management systems. However, participatory organization needs an enabling environment, and supportive policies as well. With flexibility, understanding, and commitment, a transition to sustainable forest management can take place in India.

Conclusion

A halt to rapid destruction, transition to sustainably managed secondary forests and tree plantations, and reduction in wood/forest product demand are the basic challenges that need to met to end the existing levels and methods of forest exploitation. Pressures of population, poverty, and the demands on forests seem insurmountable. The interests of governments, politicians, forest dwellers, industries, local communities, and the public are of great concern.

With its 'bottoms-up' approach, JFM has created the space for communities in contributing to the management of the nation's public forests, unlike traditional systems or even other supposedly people-based schemes like farm forestry or social forestry. Greater responsibility to local communities in forest protection, development, and management; increased share of benefits from forests to local user groups, both NTFP and wood; and regulation of grazing and illicit fellings are the cornerstones of the programme.

Programmes like JFM reflect political commitment and public support in the development and conservation process and to a halt to degrading trends of forest resources. With biological limitations to the productivity of forests for biomass enhancement, interventions like improved agricultural practices, pisciculture, population control, poverty eradication, alternative employment, alternative sources of energy specially renewable sources, all have a crucial role in stemming forest destruction, species diversity loss, global warming, and extinction of irreplaceable ecosystems. A far-reaching change is the realization of the important social content of forestry, which now suggests that all policy decisions must take into account the interests of the population and involve the people in various forestry activities to their benefit, especially the population living in the rural, and in and around forest, areas.

While SFDs are gaining the experience of the operational needs for this approach to forest management, it is probably too early to judge the success of this Programme, though ground realities in some states hold great promise.

References

Brown L R, Flavin C, Postal S. 1989. Outlining a global action plan. *In* World Watch Institute (ed.). *State of the World 1989*. A Worldwatch Institute Report on progress towards a sustainable society. New York. W W Norton and Company

Bardhan Roy B K 1993. *Wasteland to Wealth – The West Bengal Way.* Calcutta: Department of Forests, Government of West Bengal.

FAO. 1986 FAO's tropical forestry action plan. *Unasylva* 38(2): 37–64.

FAO. 1990. FAO releases new deforestation figures *Tigerpaper* 17(2): 15.

Ford Foundation 1991. Saving the forests India's experiment in cooperation *The Ford Foundation Letter* 22(1).

FSI 1995. Extent composition, density, growing stock and annual increment of India's forests. Dehra Dun: Forest Survey of India

Kaul O N, Dhar S K. 1994. Joint Forest Management in Haryana Shivaliks. Paper presented at the *International Workshop on India's Forest Management and Ecological Revival.* New Delhi: Tata Energy Research Institute.

Kaul O N, Dwivedi B N, Shah V. 1995 Ecological revival of Haryana Siwaliks through community participation. *Joint Forest Management Series* 17. New Delhi: Tata Energy Research Institute.

Lele U, Mitra K, Kaul O N. 1994. Environment, development and poverty. a report Paper presented at the *International Workshop on India's Forest Management and Ecological Revival* CIFOR Occasional Paper No 3.

MoEF 1987. *India's Forests 1987* New Delhi: Ministry of Environment and Forests, Government of India.

Murray C H. 1990. Forestry in 90s. *Tigerpaper* 17(1) 3–7

NWDB. 1988. *Report of the Committee on Fodder and Grasses* New Delhi· National Wastelands Development Board, Government of India

Postal S, Ryan J C 1991 Reforming forestry. *In* World Watch Institute (ed). *State of the World 1991* A Worldwatch Institute report on progress towards a sustainable society New York: W W Norton and Company.

Panda A, Varalakshmi V, Gupta J R, Singh B, Dabas M. 1992. Impact of participatory forest management on the ecology of Shivalik hills in Haryana state. *Joint Forest Management Series* 2 New Delhi Tata Energy Research Institute.

Rangachari R 1993. Flood management. *In* B G Verghese, R I Ramaswamy (eds). *Harnessing the Eastern Himalayan Rivers – Regional Cooperation in South Asia.* Delhi: Konarak Publishers Pvt Ltd

SPWD. 1992. *Joint Forest Management Concept and Opportunities* Proceedings of the National Workshop Surajkund New Delhi Society for Promotion of Wastelands Development

TFAP. 1990. High level TFAP review team proposes international convention on forest and tropical forest fund. *Tigerpaper* 17(2). 9–10.

Verghese B G, Iyer R, Ahmad Q K, Pradhan B B, Malla S K 1994. *Converting Water into Wealth – Regional Cooperation in Harnessing the Eastern Himalayan Rivers.* Delhi Konarak Publishers Pvt. Ltd.

WRI. 1990 *World Resources 1990–91* New York. Oxford University Press/World Resources Institute

A BIOMASS-BASED STRATEGY FOR MEETING ENERGY NEEDS IN RURAL AREAS

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Introduction

Energy is a primary input in the production of goods and services. The role of energy in contributing towards human welfare has increased in importance along with industrialization and the organized development of the service sector of modern society (Table 1). Various attempts have been made since the early 1980s to incorporate biomass in energy planning activities. There is a remarkable shift in the perception of the present and potential role of biomass in the national and rural economy. It has become increasingly important to recognize the problems and potential of biomass energy and its production.

Why biomass energy development?

In the 'energy crisis' perception of the 1970s, the negative effects on the rural subsistence economy, the deforestation effects, and the serious 'national fuel gaps' between supply and demand were predominant. Remedies for rural fuelwood problems were thought to be relatively simple such as biogas production from different kinds of wastes; more trees in the form of energy plantations; better stoves for rural families; tapping of wind, water, and solar energy for heating.

The growth and economic utilization of biomass, as an alternative to fossil fuels, has to be seriously considered. Although, traditionally, all rural energy sources have been basically derived from biomass in the form of wood and waste (65% firewood, 20% agricultural

TABLE 1
Energy–economic development nexus

Country/category	Per capita GNP ($) 1992	Per capita energy consumption (kgoe) 1992	Average growth in energy consumption 1980–92 (%)	Energy imports as percentage of merchandise exports (1992)
Part A				
World average	4280	1447	3.9 (2.5)	10
High income countries	22160	5101	1.5	10
Low income countries	390	338 (376)	5.4	9
Sub-Saharan Africa	530	258 (135)	2.9 (3.5)	7 (12)
South Asia	310	209 (289)	5.6 (7.2)	23
East Asia and Pacific	760	593	6.8	10
Middle East and North Africa	1950	1109	5.7 (7.3)	5
Latin America and Caribbeans	2690	923 (1051)	2.7	10 (13)
Part B				
Bangladesh	220	59	8 5	21 (26)
India	310	235 (337)	6.8 (7.2)	26
China	470	600	5.1	4
Philippines	770	302 (218)	3.1 (1.9)	22
Singapore	15730	4399 (6178)	6.7 (5 6)	15
Egypt	640	586	6.1 (4.6)	4 (5.6)
Saudi Arabia	7510	4463 (4866)	5.5 (9.3)	Nil
Costa Rica	1960	566 (507)	3.7	22
Brazil	2770	681 (908)	3.9 (4.7)	14 (19)
Part C				
Japan	28190	3586	2.6 (2.2)	16
USA	23240	7662	1.7(1.4)	15
Canada	20710	7912 (9390)	1.6(2.0)	4

Note. Figures in parentheses pertain to 1991.
Source. World Bank (1994).

waste, and 15% dung cake), it is only after the oil crisis that attention has been drawn to the enormous waste resulting from the direct burning of wood and the ecological and environmental problems created through massive deforestation. In fact, it is said that India may produce sufficient food grains for everyone, but unless measures are taken, it cannot provide the necessary fuel to cook the same.

Since there exists a positive nexus between energy consumption and food production, low energy consumption impinges upon the national efforts to achieve self-sufficiency in food production. Table 2 shows the consumption levels of the top 22 most populous countries (having a population of more than 50 million) and their level of self-sufficiency in food in 1979–81 and 1988–90.

Until and unless some reliable measures are adopted and a dynamic new approach in energy planning and management is vigorously promoted, a majority of the developing countries will continue to suffer from slow growth, poverty, ill health, and growing unemployment.

TABLE 2
Energy consumption and food self-sufficiency of the most populous countries[a]

Country	Per capita energy consumption (1992)	Food self-sufficiency (%)	
		1979–81	1988–90
USA	7662	168	131
Russian Federation[b]	5665	—	—
Germany	4358	82	96
France	4034	172	215
Ukraine[b]	3885	79	85
UK	3743	94	110
Japan	3586	28	26
Italy	2755	75	81
Mexico	1525	83	74
Iran[c]	1256	76	68
Turkey	948	102	97
Brazil	681	83	89
Thailand	614	153	140
China	600	95	98
Egypt[c]	596	55	56
Indonesia	303	90	95
Philippines[c]	302	91	83
India	235	96	106
Pakistan	223	112	97
Nigeria	128	79	97
Bangladesh[c]	59	88	87
Ethiopia[c]	21	99	87

[a]population more than 50 million; [b]USSR combined; [c]the most vulnerable countries, with sizeable food imports.
Source. Per capita energy consumption figures: World Bank (1994); food self-sufficiency figures: FAO (undated).

The most preferred fuel – electricity – is plagued with heavy slippage in India with the targeted production always falling short. Table 3 shows the planwise slippage in power production. In addition, heavy transmission and distribution losses averaging 22% add to the growing energy starvation. Although, there has been an increasing allocation of funds for the power sector – now accounting for about 30% of the total plan funds – the rural areas gain only marginally. So far, only 27% of the households in the villages have been electrified.

Oil production in India is constantly falling short of demand. From a peak of 34.09 million tonnes (mt) in 1989/90, the production has slipped down to 26.95 mt. It is targeted to go up to 44.45 mt in 1996/97 By then the total demand for oil and petroleum products is expected to touch 80 mt.

TABLE 3
Plantwise slippages in the power sector in India

Plan	Target (MW)	Achievement (MW)	Slippages (%)
First plan (1951–56)	1300	1100	15.4
Second plan (1956–61)	3500	2250	35.7
Third plan (1961–66)	7040	4520	35.8
Annual plan (1966–69)	5430	4120	24.1
Fourth plan (1969–74)	9264	4579	50.5
Fifth plan (1974–79)	12499	10202	18.4
Annual plan (1979–80)	2945	1799	38.9
Sixth plan (1980–85)	19666	14226	27.7
Seventh plan (1985–90)	22245	21402	3.8
Annual plan (1991–92)	4212	2776	34.1

Source. CMIE (1991).

Preponderance of biomass energy sources

The World Energy Conference held at Delhi in 1994 had categorically highlighted the excessive dependence on the traditional biofuels in Asia and Africa in its report. It had further pointed out that there is not going to be any let-up for a long time to come. The Advisory Board on Energy, in its report, *Towards A Perspective on Energy Demand and Supply in India in 2004–05*, had sounded the grave warning that even in the early 21st century, there would be a preponderance of non-commercial energy sources.

Biomass from plants: the photosynthetic pathway

Most of the developing countries located in and around the tropics receive plenty of light. This makes the photosynthetic pathway the most desirable and efficient energy option for the Third World countries. Among all the new and additional sources of energy, it is biomass, and bioenergy derived therefrom, when promoted and produced in a decentralized manner, that could eventually turn the tide favourably, and lead to rapid growth, with the added benefit of year-round employment for the needy millions (Table 4).

Green plants are a naturally available option that transforms atmospheric CO_2 into carbohydrate from which ultimately we get energy:

$$6\ CO_2 + 6\ H_2O \xrightarrow{\text{Light}} C_6H_{12}0_6 + 684\ \text{kcal}$$

Generally, in common fuels, such as wood, carbon (C) and hydrogen (H) are available in the form of cellulose, hemicellulose, and lignin, with carbon burning easily. When wood is directly burnt, at the most, 13% of total energy is utilized and with improved *chulhas*

TABLE 4[a]
Biomass systems

Advantages	Problems
Stores energy for use at will	Land use competition
Renewable	Large areas required
Dependent on technology already available, with minimum capital input	Supply uncertainty in initial phase
Can be developed with present manpower and material source	Fertilizer, soil, and water requirement
Reasonably priced	—
Ecologically inoffensive and safe	—
Does not increase atmospheric CO_2	—

[a]adapted from Hall (1979).

(cookstoves), this efficiency is raised. However, the volatile matter emitted as smoke and soot are wasted and become pollutants. In the 1970s, Gunnerman of USA developed small wood pellets called *woodex* from wood waste. *Woodex* is nothing but a concentrated form of carbon and can be burnt thoroughly. It is environmentally clean, particularly with regard to a potent pollutant – sulphur.

The global biomass production of 200 billion tonnes can yield 3×10^{21} joules of energy per annum, which is about 10 times the total world energy consumption. Thus, biomass can become a resource that is far cheaper, easily renewable, pollution free, and something that easily conforms to the very ethos of the developing countries.

With meticulous planning, biomass can definitely help micro-regions become virtually self-sustaining 'energy republics'

Making an inventory of biomass resources, one is amazed at the rich diversity that is to be found in any and every source, ranging from agro-horticultural wastes and animal wastes to forestry and fishery wastes, besides agro-industrial wastes. The diverse bioresources and their potential for energy is shown in Table 5.

Crop residues and agro-wastes form the most easily available and economically renewable resource. Table 6 lists the availability of major crop residues in India during the last decade.

Conclusion

As can be seen, biomass has enormous potential as an energy source. However, proper planning, research, and development is necessary to exploit it fully. In view of the fact that biomass would continue to remain the main option for the majority of the population in the country, it is imperative to promote efficient biomass technologies in a systematic way.

TABLE 5
Potential biomass resources and their yield potential

Types	Potential
Trees/wood	
Leucaena leucocephala	50 m³/ha/year; many species yield
Acacia sp.	20 m³ of wood/ha/year when grown on reasonably good soil
Colliandra sp.	
Sesbania sp.	
Eucalyptus sp.	
Casuarina sp.	
Hydrocarbon plants	
Euphorbia group	
Euphorbia lathyrus	17 barrels/ha/year on semi-arid land
Euphorbia tirucali	36 barrels/ha/year
Oil-producing species	
Soyabean	Can grow on a wide range of soils and
Sunflower	climatic conditions; fuel for diesel engines or as blend
Groundnut	
Sugar/starch crops	
Sugarcane	50 tonnes of sugarcane per ha/year can yield 120 tonnes/ha (Hawaii) giving a yield of 3600 litres of alcohol/ha
Sweet sorghum	45 tonnes/ha/year can yield 3500 litres of alcohol/ha
Cassava	Poor soils; 10–20 tonnes/ha/year can yield 2160 litres of alcohol/ha
Other crops	
Corn	6 tonnes/ha can yield 2200 litres
Green herbaceous plants	
Tropical grass	High cellulose content; not good for alcohol; could be useful for charcoal, as feedstock for gas or liquid fuel
Elephant grass (Napier grass)	
Imperate cylindrica (Asia)	
Aquatic crops	
Water hyacinth	Animal feed/energy use (biogas) plus fertilizer
Duckweed	50 tonnes/ha/year (dry matter)
Seaweeds	Source of food; can be used for energy as well as for fuel; 90 tonnes/ha
Seakelps	For gas generation (CH_4); according to an estimate, each hectare of kelp could yield 10 million kcal of food

TABLE 6
Potential availability of agrowastes in India

Crop	1981–82	1989–90
Rice	53284	74053
Rice straw	26624	37027
Wheat	37452	49652
Wheat straw	49811	66037
Maize	6897	9409
Maize cobs	2069	2823
Bajra	5537	6620
Bajra straw	9191	10989
Ragi	2961	2781
Ragi straw	14213	13349
Small millets	1638	1121
Millet straw	4177	2836
Sugarcane production	186358	222628
Bagasse available	62119	73467
Coconut production (million nuts)	5573	8163
Coconut shell	752	1102
Coconut fibre	914	1338
Coconut pith	1371	2008
Groundnut production	7223	8088
Groundnut shell	2407	2669
Cotton production ('000 bales· 70 kg each)	7884	11414
Cotton stalks	24171	21993
Jute production ('000 bales· 180 kg each)	6788	7112
Jute sticks	2478	2037

References

CMIE 1991 *Current Energy Scene in India* Bombay· Centre for Monitoring Indian Economy
Hall D O. 1979 Plants as an energy source *Nature* **278**: 114–17
World Bank. 1994 *World Development Report* Washington, DC. The World Bank

FUEL CHARACTERISTICS OF SOME INDIGENOUS WOOD SPECIES OF NORTH-EAST INDIA

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Introduction

Fuelwood has been a major source of energy for a very long time, and its demand is expected to increase enormously in the coming decades. Indeed, fuelwood is likely to continue as the most important fuel for rural areas in developing countries. Fuelwood, if better managed and utilized, could rapidly increase the energy available to developing countries. A logical response to the fuelwood situation is to plant more trees. However, while selecting the tree species for plantation, special attention should be given to the species traditionally preferred for fuel.

Fuel characteristics of a large number of promising fuelwood species of the humid tropics, the tropical highlands, and the arid and semi-arid regions have been recorded in a recent report of National Academy of Sciences, Washington, DC (1980). In India, the calorific values of some plants of tropical deciduous forests have been determined by Desh Bandhu (1971), Sharma (1972), Foruqi (1972), and Singh, Pandey, Upadhyaya (1982). Fuwape (1989) reported that removal of extractives from plants caused a reduction in the quality of heat per unit mass. In the forests of north-east India, there exist a large number of tree species whose fuel characteristics are not known. The present paper describes the fuel characteristics of four different plant species, which are traditionally preferred for fuel by the rural people of this region. An attempt is also made to examine the effect of different biochemical components of the plant materials on their calorific values.

Materials and methods

Four tree species, *Albizzia lucida* Benth. (family – Leguminosae), *Syzygium fruticosum* Roxb. (family – Myrtaceae), *Pterospermum lanceaefolium* Roxb. (family – Sterculiaceae), and *Premna bengalensis* Clarke (family – Verbenaceae), were selected for this study. The description of these plant species have been provided in Kanjilal, Kanjilal, Das (1940).

The wood, bark, twig, and leaf samples of the plant species under study were collected from the forests of the Jorhat district of Assam during the month of September. The age group of mature trees ranges from 15 to 25 years. For each of the species, a disc of about one inch thickness was cut from the trunk wood of freshly felled trees. Freshly removed trunk bark samples and twigs of diameter varying from 1 to 10 cm size were used for the experiments. Mature leaves of the trees were also collected randomly and used in the experiments.

The moisture content of the different plant parts was determined according to the method described in Wenger (1984). Specific gravity of the samples was determined by the method described in IS: 1708-1969 The ash content, solubility in cold water, the alcohol–benzene extractive content, and the lignin content in the plant parts were determined according to TAPPI standard methods: T 211 om-85, T 207 om-84, T 204 om-88, and T 222 om-88 respectively To determine the cellulose content, the method described by Browing (1967) was followed. The method of van Beckum and Ritter, modified by Timell, Glandermans, Gilham (1959), was used for determination of holocellulose The calorific values of the samples were determined by the ISI method using a bomb calorimeter.

Results and discussion

Various important fuel characteristics such as moisture content, specific gravity, ash content, cold water solubility, and the calorific values of the plant parts of the four species are given in Table 1 The alcohol–benzene extractive content, the lignin content, the cellulose content, and the holocellulose content of the plant parts are given in Table 2.

From Table 1, it is clear that the moisture content in all the parts of *Premna bengalensis* is much higher compared to the other three species The trunk bark and the leaves of all the plants produced a higher percentage of ash than the wood and the twigs. The trunk bark portions of all the plants contained the highest percentage of cold water soluble materials, whereas the twigs contained the lowest percentage. The lignin content in all the parts of *Premna bengalensis* was found to be lower than the other three plants. However, its bark contains a higher percentage of holocellulose The leaf samples of all the plant species contained a high percentage of the alcohol–benzene extractive which consists of substances such as waxes, fats, resins, photosterols, non-volatile hydrocarbon, low molecular-weight carbohydrates, salts, and other water soluble substances.

Every content of fuelwood is measured by its calorific value. The calorific value of a plant is a function of its genetic constitution, nutritive condition, and life history. This value varies with the light intensity, the length of daylight, the amount of nutrients, and the

TABLE 1
Some important fuel characteristics of the plant parts

Species (botanical name)	Plant parts	Moisture content (percentage weight)	Specific gravity	Ash content (percentage oven-dry weight)	Cold water solubility (percentage oven-dry weight)	Calorific value (kcal/kg dry weight)
Albizzia lucida	Trunk wood	42.81	0.671	1.09	4.03	4835
	Trunk bark	63.34	0.592	6.93	6.62	3885
	Twig	54.19	—	2.11	1.02	4170
	Leaf	50.21	—	3.24	3.19	4945
Syzygium fruticosum	Trunk wood	43.72	0.741	0.97	4.61	4855
	Trunk bark	64.16	0.684	7.12	5.15	3795
	Twig	52.27	—	2.31	0.96	4325
	Leaf	51.17	—	4.05	3.79	4890
Pterospermum lanceae-folium	Trunk wood	43.97	0.649	0.91	3.72	4830
	Trunk bark	64.29	0.638	7.78	6.07	3915
	Twig	53.81	—	3.07	0.97	4720
	Leaf	51.65	—	3.81	4.05	4890
Premna bengalensis	Trunk wood	57.16	0.507	1.93	5.62	4455
	Trunk bark	71.20	0.371	9.29	8.75	3830
	Twig	60.11	—	4.08	1.67	4230
	Leaf	66.14	—	11.62	4.97	4555

TABLE 2
Major biochemical constituents of the plant parts

Species (botanical name)	Plant parts	Extractive content (percentage oven-dry weight)	Lignin content (percentage oven-dry weight)	Cellulose content (percentage, oven-dry weight)	Holocellulose content (percentage oven-dry weight)
Albizzia lucida	Trunk wood	1.85	33.20	58.32	66.40
	Trunk bark	4.47	31.05	21.47	38.16
	Twig	1.91	22.17	15.40	48.21
	Leaf	2.97	29.19	24.52	35.11
Syzygium fruticosum	Trunk wood	1.43	30.97	60.17	65.73
	Trunk bark	2.96	30.05	21.94	40.53
	Twig	1.61	21.63	12.19	47.46
	Leaf	3.31	27.97	27.17	34.16
Pterospermum lanceae-folium	Trunk wood	1.94	28.46	59.14	67.81
	Trunk bark	3.14	25.31	20.12	40.72
	Twig	0.99	24.17	13.63	45.10
	Leaf	3.74	26.25	21.25	32.95
Premna bengalensis	Trunk wood	3.53	21.14	63.20	73.66
	Trunk bark	2.61	20.07	18.54	53.17
	Twig	1.99	19.79	19.36	48.97
	Leaf	4.62	17.95	28.85	37.41

type of soil in which they grow (Golley 1961; Long 1934) It is also dependent on the ash content and the biochemical constituents. According to Fuwape (1989), lignin in plants contributes positively to the heating value whereas cellulose reduces it.

From Table 1, it can be seen that the calorific values vary in different components of the plant species. The leaf shows higher calorific values (4555–4945 kcal/kg) in all the plant species as compared to other components. The high calorific values of the leaf samples may be due to their high extractive content and low cellulose content. The bark shows the lowest calorific values (3795–4005 kcal/kg) which may be due to its high ash content A similar trend of variation of calorific values of plant parts of other plant species were observed by Foruqi (1972)

From the results of the present study (Tables 1 and 2), it can be concluded that *Albizzia lucida*, *Syzygium fruticosum*, and *Pterospermum lanceae-folium* are very good plant species so far as fuel characteristics are concerned. Among these plant species, *Albizzia lucida* appears to be the best one. Further, this plant has excellent coppicing quality. Further work is necessary to study their growth rates, planting density, rotation period, productivity, etc., before including these plant species under the energy plantation programme

References

Browing B L 1967 *Methods of Wood Chemistry* 2: 403–405

Desh Bandhu. 1971. A study on productive structure of tropical dry deciduous forests at Varanasi. PhD Thesis Varanasi: Banaras Hindu University

Foruqi R. 1972 Organic structure and productivity of plantation of Sal (*Shorea robusta* Gaerin.) and Teak (*Tectona grandis* Linn.) PhD Thesis Varanasi: Banaras Hindu University

Fuwape J A. 1989 Gross heat of combustion of *Gmelina arborea* R chemical components. *Biomass* 19· 281–287

Golley F B 1961. Energy values of ecological materials. *Ecology* 42 581–584.

Kanjilal U N, Kanjilal P C, Das A 1940 *Flora of Assam*. Vols I, II, and III, Government of Assam

Long F L 1934 Application of calorimetric methods to ecological research. *Plant Physiology* 9. 323–337.

National Academy of Sciences 1980 Firewood crops shrub and tree species for energy production Report of an Ad hoc Panel of the Advisory Committee on Technology Innovation Washington, DC National Academy of Sciences.

Sharma V K. 1972. Ecology of *Shorea robusta* Gaerin and *Buchanania lanzan* Spreng at Varanasi forests. PhD Thesis. Varanasi Banaras Hindu University

Singh R P, Pandey S N, Upadhyaya A K 1982 Calorific values of plant materials from tropical dry deciduous forests in Chandraprabha region. *Indian Journal of Forestry* 5(1) 64–69

Timell T E, Glandermans C P J, Gilham J K 1959 *TAPPI* 42 62

Wenger K P. 1984. *Forestry Handbook*. pp. 565–635. Second edition John Wiley and Sons Inc

ENERGY FROM BIOMASS: PROSPECTS IN INDIA

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Introduction

Biomass has now emerged as a potential renewable energy source. The fast depletion of fossil fuels and large-scale deforestation have created serious energy crises in the developing nations. The situation is grave in countries like India where a large proportion of population, particularly the poor, depend on biomass for the satisfaction of their energy requirements. Biomass as a source of energy is environment friendly, renewable, relatively cheap, and locally available. Considering the merits and importance particularly for the poorer strata, there is an urgent need to make available technologies for increasing the productivity of biomass and ensure its efficient utilization. This would go a long way in promoting the sustainable use of biomass for meeting energy requirements, and would also result in additional benefits to the society in terms of employment generation in the form of personnel for processes like plantation, maintenance, collection, storage, and transportation.

Availability of biomass in India

As per the Ministry of Non-conventional Energy Sources (MNES), several thousand megawatts of power can be generated from biomass alone. The total amount of biomass produced annually is about 1249 million tonnes. It is estimated that 1000 hectares of land can generate 3 MW of power. Energy plantations should, therefore, be coupled with power generating units based on gasifiers and Stirling engines to form integrated energy-cum-power projects which can provide fuelwood as well as power. It is estimated that 2000 MW

of power can be generated only from sugar bagasse. Power can also be made available from systems based on agricultural waste yielded by sugar, rice, pulses, and similar crops, through newer techniques at competitive costs. It has been proposed that 6000 MW of power will be generated through biomass by the year 2001. Furthermore, the 93 million hectares of wastelands that India has can be efficiently put to use for raising bioenergy plantations, thereby generating employment in the process. According to MNES, there is a potential of 17 000 MW equivalent biomass/bioenergy in the country, out of which 3500 MW is from cogeneration. In addition, there is a potential of 1000 MW that can be realised from urban and industrial wastes, out of which only a very small portion has been tapped so far for commercial applications.

R & D efforts: what needs to be done

It is clear that there is an enormous untapped potential for energy generation from biomass. What is required is an immediate intensification of basic R & D efforts in this field, in view of bringing down the unit energy costs and improving efficiencies and reliability of biomass production, conversion, and utilization An effective R & D programme must envisage the points outlined below.

- Identify and evolve fast-growing fuelwood species, suitable particularly for plantation in wasteland/degraded lands. These programmes can be directed so as to generate local employment so that the rural poor emerge as the real beneficiaries.
- Exploit the possibilities of utilizing agro-wastes, residues, and hydrocarbon plant species to produce alcohol for use in the transportation and industrial sectors.
- Development and improvement of gasification, biomethanization, and briquetting technologies, and the development of their linkages with a variety of end-uses, such as providing drinking water, and for water pumping, domestic lighting, cooking, heating, and industrial purposes.
- Effective utilization of industrial wastes, such as bagasse, dairy wastes, etc., for power production, and efficient utilization of this power by the industries themselves or as a means of revenue generation by selling the surplus power.
- Effective utilization of municipal sewage for power production. The anaerobic technology of sewage treatment generates methane. This technology needs to be efficiently promoted (as compared to the aerobic treatment processes currently used) to generate surplus power that can be fed to the grid.
- Utilization of solid wastes in the urban centres for power generation. At present, most Indian cities are confronted with the problem of disposing domestic urban waste. Most of them lack an organized solid waste management system. For example, Bhopal, the capital city of Madhya Pradesh, with a population of 1.1 million and generating nearly 300 tonnes of domestic waste daily, has no organized system of refuse collection – leave alone other aspects of waste management. The scene in such developed cities is pathetic with refuse often dumped on roadsides. This waste can be effectively used to generate wealth through utilization for power generation.

Conclusions

Many of the above R & D programmes have already been initiated, but what is required is an air of urgency in our efforts. It would be prudent to couple these programmes with employment generation schemes to fulfill our social obligations – it would be a massive waste of efforts in case the benefits do not reach the poorest of the poor. Also required is the launching of an awareness campaign to involve wider sections of the society in the biomass programmes. Besides carrying out the R & D efforts and promoting the end-uses of the energy generated, the various engineering and technological institutions can be of immense help in providing linkages and ensuring wider public participation in such programmes.

APPLICATION OF THE GEOGRAPHIC INFORMATION SYSTEM IN DECENTRALIZED ENERGY PLANNING

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Background

The present pattern of economic growth has led to severe degradation of environmental quality and rapid depreciation of natural resources. Hence, the need for urgent solutions that promote sustainable development. It is in this context that the concept of decentralized rural energy planning has assumed significance in the past decade, with the promotion of area-based (with the district as a unit) energy intervention programmes. The district is considered the appropriate unit as most programmes are implemented at this level. This approach pays adequate attention to the variations in socio-economic cultural factors at the micro-level, and has thus led to a more equitable allocation and utilization of available resources in rural areas. Further, it has also facilitated the incorporation of parameters specific to different ecosystems that are likely to exist within a district.

The concept of decentralized energy planning has multiple facets, as it not only aims to provide for energy needs at the local level, but also has a direct impact on environment, energy conservation, employment generation, upgrading health and hygiene conditions, and women's welfare. Self-sustainability in energy supply can be attained by conserving energy and by producing additional energy A logical plan would aim to have an equitable distribution of benefits, conserve energy; mitigate environmental degradation, generate employment; and lead to an overall improvement in the quality of life. The present study shows how an advanced tool like the Geographic Information System (GIS) could be used to develop biomass-based energy plans at a decentralized level. The Changlang district of Arunachal Pradesh in the north-eastern region of India is the site of the study

Introduction to GIS

GIS is one of the most powerful computer software-based analytical tools to emerge in the past decade. It is a spatial data management tool, which acts as a visual decision support system and a perfect tool to see patterns and exceptional situations on the ground reflected on the computerized maps. It has the ability to carry out spatial operations, and link data sets using the location as the common key. Basically, GIS explains five generic questions: *location* (What exists at a particular location; it can either be the name of place or the latitude or longitude.); *condition* (Where is this condition going to be satisfied? This is done by spatial analysis.); *trends* (What has changed in area between two timeframes?); *patterns* (What are the spatial patterns that exist?); and *modelling* (Mostly used by the planners and policymakers, provides answers for what would happen if some criteria are included.).

ARC/INFO is one of the most popular software packages used in GIS applications. The application of GIS begins with the creation of a digital map database. Once the maps are digitized and automated, information that needs to be stored and recorded, and the exact usage of the map, is structured. GIS has a specific data model for representing maps in the computer. The information conveyed by a map is represented graphically as a set of map components. These are stored as a point line, or arc feature. Once the map has been automated and the data structured, the maps are then overlaid as per the needs of the planners. It is at this stage that the ARC/VIEW software is used, which gives the view of the automated map, exhibiting all the features designed. Criterion-based analyses are performed at this stage in ARC/VIEW, depending upon the objective of the study. Figure 1 gives the schematic representation of the GIS-based approach for improved *chulhas* (ICs) and biogas plants. It explains the coverages (maps) developed and the criteria-based analysis done to develop the target plan of ICs and biogas plants for the district. The relevant maps prepared as part of the analysis are given at the end of this paper.

District profile

The Changlang district in the state of Arunachal Pradesh is located in one of the remotest corners of India The district is bound on the east and on the south by Myanmar, on the north by Lohit district of Arunachal Pradesh, on the north-west by Dibrugarh district of Assam, and on the south-west by the Tirap district of Arunachal Pradesh. It covers an area of 4662 km^2, and supports a population of 95 530 (with population density of 17 persons/km^2). The district is divided into 10 administrative circles covering 286 villages. The Naoh-Dihing and the Tirap rivers constitute the main drainage systems of the district.

Indigenous communities constitute more than two-thirds of the total population. These include the Tangsa, Tutcha Nocte, Singpho, Khamti Lisus, and Millang. Apart from these, Chakmas, Tibetans, Nepalese, Lisus, and people from other parts of the country and continent constitute the district population. TERI has conducted a rural energy planning study in this district, jointly sponsored by the Ministry of Non-conventional Energy Sources, the North Eastern Council, and the Rural Works Department of the Government

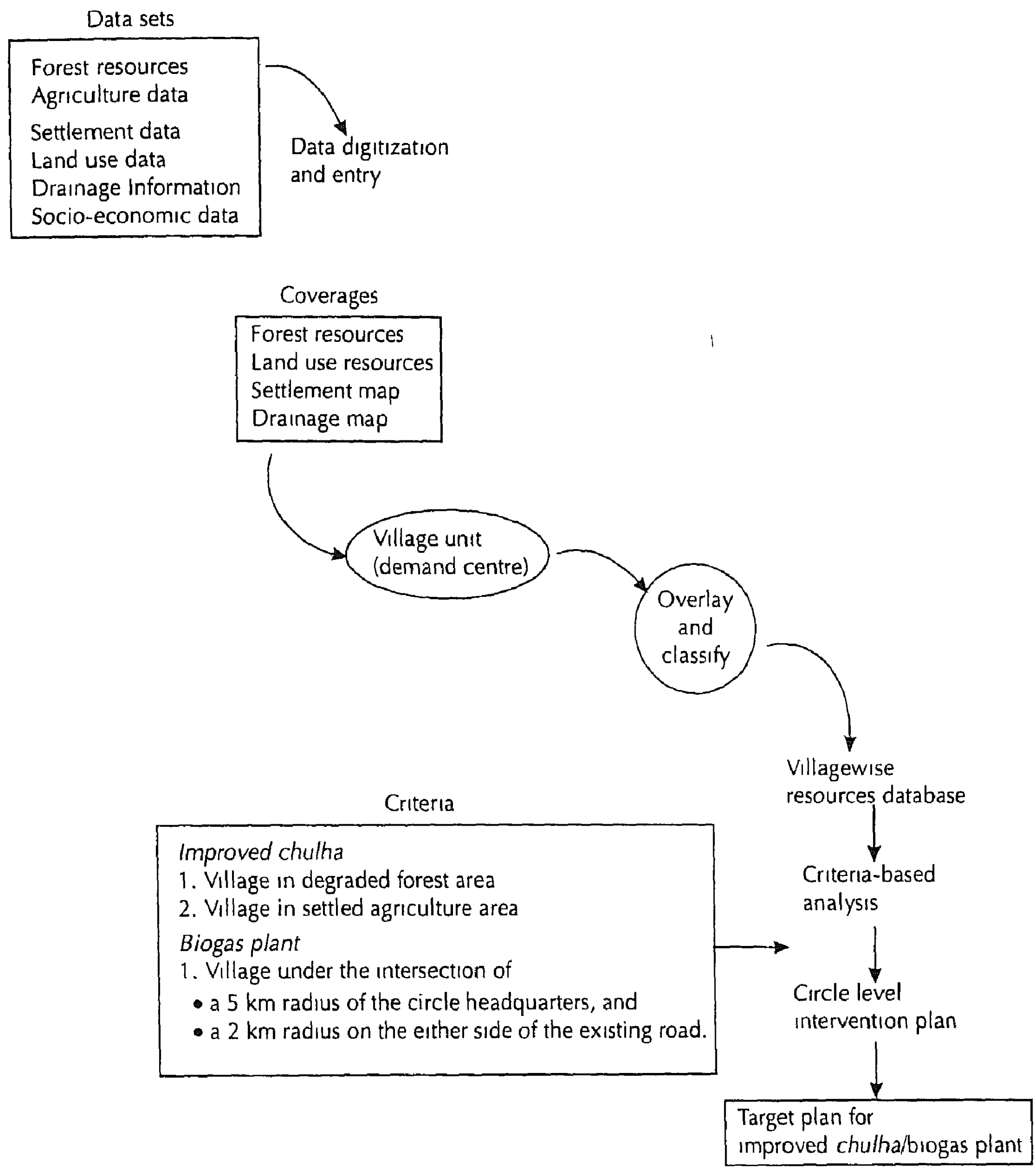


Figure 1. GIS-based approach for improved *chulhas* and biogas plants

of Arunachal Pradesh. Changlang was selected for its composite topography, richness in biomass resources, its remote location, and the fact that the entire district is predominantly a rural settlement. 31 of the 286 villages in the district were studied, wherein 212 households were surveyed. The households in the district largely depend upon fuelwood to meet their energy requirements, with nearly 96% of the households using fuelwood to meet their cooking requirements. The supply of commercial fuels is very poor, as is indicated by the low per capita consumption of kerosene and electricity. The per capita annual consumption of kerosene is 3.9 litres, and the per capita annual electricity consumption is only 25.3 units.

Existing fuelwood consumption pattern

The per capita annual consumption of fuelwood in the district is 2.17 tonnes This may not sound very alarming, with a sustainable yield of 28 lakh tonnes per annum (29 tonnes per capita). However, this sustainable yield can be misleading as:

- 60% of the forests are under the Reserve Forest category with high crown density, which is included in the calculation of sustainable yield;
- growing population pressure is rapidly bringing about an increase in forest area under *jhum* (slash and burn) cultivation, earlier the *jhum* cycle was between 15 and 20 years, but at present the cycle has reduced to 5–7 years, and
- the number of sawmills and plywood industries in the district is growing at a fast rate – from only two such industries in 1990 to 11 by 1994.

Improved *chulhas*

The villagers in Changlang district use the open hearth type fireplace with an iron tripod in the middle to support the utensils, resulting in very low thermal efficiency of one to two per cent (Figure 2) This pattern of energy use requires a large quantity of firewood and leads to excessive thermal loss, as the flames flicker and lack direction. Such traditional *chulhas* serve the purpose of lighting as well as space heating, and consume a large quantity

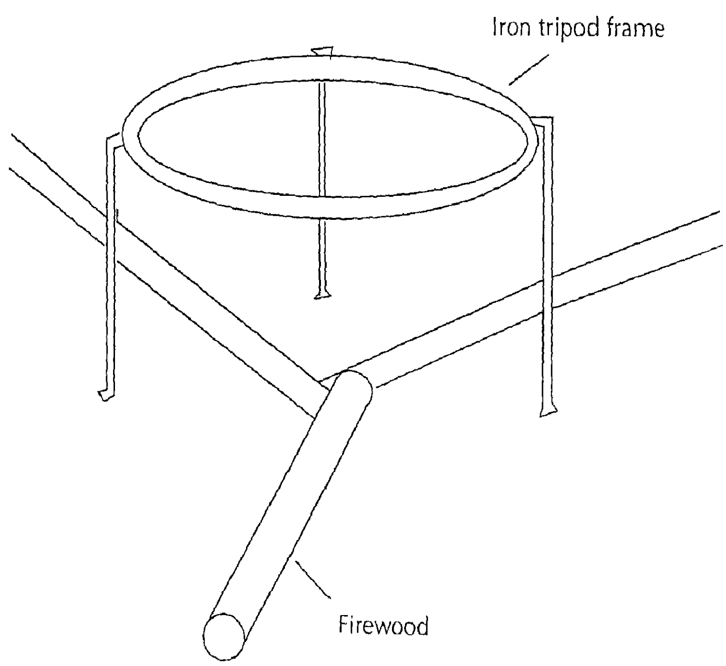


Figure 2. Traditional household *chulha* in Changlang

of firewood. The smoke is used for drying foodstuff and firewood, as a protective agent for thatched roofs, and as an insect repellent.

Using the present per capita consumption and population growth rate (4.4% per annum), it is projected that the per capita annual consumption of fuelwood would be 2.27 tonnes. Increase in population is also an indication of more stress on forest resources and more area being brought under *jhum* cultivation. This increase in the fuelwood consumption, and the expected increase in the *jhum* areas, will lead to fuelwood scarcity in certain villages and areas in the plains. Also, given the present level of awareness and perception of the villagers, it is expected that there would be hardly any change in their fuelwood extraction and consumption patterns. Thus, there is definitely a need for intervention (in the form of ICs), which not only creates awareness regarding depletion of resources, but also leads to more effective and better utilization of the existing biomass resources.

The improved *chulha* plan

The objective of designing an IC plan is to provide for efficient utilization of fuelwood, which is mainly used for cooking and space heating. Thus, the steps taken into consideration for identifying the areas feasible for implementation of ICs are based on the physiography, land use, agricultural practices, and the socio-economic and energy needs of the people. The target potential of ICs is for the plan period 1996–2002. The following steps were considered for the IC plan.

- *Step 1.* Using the primary survey information and the total number of households in the district, the total potential in each of the circles (administrative blocks) was obtained. The total potential of ICs in the district worked out to 13 220 (Table 1).
- *Step 2.* Since there is a low awareness (only nine per cent of the households in the hilly areas and 20% of the households in the plains were aware of benefits of energy savings), it would not be logical to have a plan which is timebound and proposes to realize the total potential of over 13 000 ICs. Two criteria were used in the analysis done to identify the villages in both plains and hilly areas

TABLE 1
Total and identified potential of ICs

Block	Total potential	Identified potential
Nampong	530	25
Vijoynagar	600	30
Khimiyang	540	50
Manmao	480	270
Changlang	1080	290
Miao	4160	1360
Diyun	3360	2190
Bordumsa	2470	2345
Total	13220	6560

- *Step 2.1.* Land use and agricultural maps of the district were prepared and the areas such as dense forest area, degraded forest area (land use map), and *jhum* land and settled agricultural areas (agricultural map) were demarcated.
- *Step 2.2.* The first criterion – villages in the degraded forest area – was used to identify the villages in the hilly areas of the district: Changlang, Khimiyang, Manmao, Nampong, and Vijoynagar. The reason behind selecting this parameter was that in most of the villages in these areas, *jhum* is practised, and with the reduction in the cropping cycle, it is expected that there would be more stress on biomass in future.
- *Step 2.2.1.* The land use map was superimposed on the settlement map (village map) Using this, the total number of villages in the degraded forest area was identified. The identified potential of ICs (number of households) in these villages was also calculated.
- *Step 2.2.2.* Using the preference rate (nine per cent of the households in the hilly areas), the target potential of improved *chulha* was obtained (Table 2). Though three circles – Nampong, Vijoynagar, and Khimiyang – satisfy the criteria, these have been excluded from the plan because of very low potential. The target potential of ICs in the remaining two areas – Changlang and Manmao – is 50 ICs. The low potential is because of low awareness among households and availability of abundant biomass.
- *Step 2.3.* The second criterion included villages in the plain areas where settled agriculture is practised: Miao, Diyun, and Bordumsa. A primary survey analysis of the fuelwood collection pattern indicated that in these areas a person travels an average 4 km per day and collects fuelwood four days a week. The average headload carried is 30 kg per trip. The fuelwood collection practice indicates that there is a higher stress on biomass in these areas, and, hence, the need for intervention.
- *Step 2.3.1.* The land use map and the agricultural map were superimposed, and the areas where settled agriculture is practised were demarcated
- Step 2.3.2. The settlement map (village map) was superimposed on the map obtained in Step 2.3.1, and the villages falling in the settled agricultural area were iden-

TABLE 2
Identified and target potential (1996–2002) of ICs

Block	Identified potential	Target potential (using preference rate)
Nampong	25	—
Vijoynagar	30	—
Khimiyang	50	—
Manmao	270	20
Changlang	290	30
Miao	1360	300
Diyun	2190	400
Bordumsa	2345	500
Total potential	—	1250
Arunachal model of IC		1200
Khirmey model of IC		50

tified (Table 1) The identified potential of ICs (number of households) was obtained.

- *Step 2.3.3.* Using the preference rate (20% of the households), the target potential of ICs in the plain areas was obtained. The target potential of ICs in the plain areas is 1200 (Table 2) The higher potential here was more due to the perceived scarcity of fuelwood by the households and the difference in their lifestyles

Improved *chulhas*: what needs to be done?

The easy availability of fuelwood in most of the regions has been one of the major reasons for the earlier failure of the IC programme in the district Furthermore, the bamboo flooring of the raised floor houses fails to provide the firm base essential for the construction of the fixed models of ICs. Keeping these points in view, the two new ICs models developed and tested by the Rural Works Division (the agency responsible for disseminating renewable energy technologies in the state) – the Arunachal model and the Khirmey model – have been recommended as part of the plan. As per the laboratory results conducted by the Technical Back-up Unit (TBU), the Arunachal model and the Khirmey model have thermal efficiencies of 30 and 24%, respectively The Arunachal model is more suitable for the plains, while the Khirmey model is suitable for the hilly regions as it is not only designed for cooking but also for space heating Both the *chulhas* are made of cast iron and have a long life.

Biogas systems

In the past, the biogas plants in the districts were installed mainly for demonstration purposes However, the programme has not been without problems The major detriments include the loss of dung due to open grazing practices and low-calorie and low-protein grass leading to low dung yield from cattle Apart from this, the climatic conditions in the district are such (mean average temperature during winters is 10–15 °C) that the hydraulic retention time (HRT) period for these plants is as high as 55 days The physiography of the district is distinct, in the sense that part of the district is plains and the rest is hilly with run-off zones Though a potential for biogas plants exists, it is highly concentrated in the plain areas of the district. The most suitable model of biogas plant for this district is *Deenbandhu* or the fixed-dome model, because of functional and technological reliability

The biogas plan

The objective of designing the biogas plan is to lead to a more effective utilization of the available dung, which, at present, is used only as farm manure by the households The rearing practices are such that the cattle are not stall-fed as a result of which nearly 30% of the available dung per day is lost Apart from cattle (cows and bullocks), pigs constitute a

major proportion of the livestock population in these households; hence both cattle and pig wastes have been included in the estimate. Primary survey results show that the collectible dung in the case of cows and bullocks is 60% of the available dung and in the case of pigs only 15%.

- Average daily availability of dung – cows: 10 kg; bullocks: 10 kg
- Average daily availability of pig wastes: 3 kg
- Collectible dung – cattle (cows and bullocks): 6 kg/day; pig: 0.3 kg/day

The following steps explain the methodology for the estimation of biogas plant potential.

- *Step 1.* Effective cattle head (ECH) for each of the surveyed households was calculated using the average daily collectible dung ECH was calculated using the following equation:

  ECH = (Number of cows × cowdung/cowdung) + (Number of bullocks × bullock dung/cowdung) + (Number of pigs × pig dung/cowdung)

- *Step 2.* The plan was designed for a 2 m^3 family biogas plant, the average dung required daily for which is 50 kg. But keeping in mind the problems of availability of dung and dung collection practices, it was assumed that for the operation of a 2 m^3 biogas plant, the minimum ECH required would be 12 cattle heads. Using the ECH for the surveyed households, data distribution was done to obtain the number of households with cattle heads more than 12. The fraction of households (f_i) having cattle heads more than 12 was calculated (Table 3).

  $f_i = N_{i2} / \sum N_i, i = 1 \text{ to } 12$

TABLE 3
Total and identified potential of biogas plants

Block	Fraction of households	Total potential	Identified potential (GIS)
Bordumsa	0.41	1200	700
Changlang	0.07	200	100
Diyun	0 40	1550	700
Khimiyang	0 17	100	20
Manmao	0 13	90	30
Miao	0 29	1360	600
Nampong	0.05	100	30
Vijoynagar	0.17	100	20
Total	—	4700	2200

where N_{12} = number of households with cattle heads more than 12
N = total number of households in the data distribution

- *Step 3.* The fraction of households (f_i) was multiplied with the total number of households to obtain the total number of households in each of the circles (Table 3). Circle-level estimation had to be done because village-level cattle holdings were not available As a result of this, it was not possible to calculate the potential of biogas plants in each of the villages. Criterion-based analysis was done using GIS to estimate the identified potential and then the target potential.
- *Step 4.* Here, first the settlement map (village map) was superimposed with the land use and the agricultural maps. This was used to identify the regions where availability of water would not be a problem, especially if settled agriculture is practised (in biogas plants, the proportion of water and dung required is 1.1)
- *Step 5.* On the map obtained in the Step 4, the drainage map was superimposed to clearly demarcate the areas where groundwater potential is good. Using this, villages were identified where groundwater potential would be able to sustain the feasibility of the biogas plant. In these villages, the identified potential of biogas plants (Table 3) was calculated using the fraction of households (f_i).
- *Step 6.* The past experience of implementation of biogas plants had problems mainly because of lack of maintenance systems, which was mainly due to logistical constraints. Therefore, at this stage, two criterion-based analyses were done to identify the villages where initially the biogas plants can be installed during the plan period: (i) villages in the radius of 5 km from the circle headquarters and (ii) villages in the radius of 2 km buffer zone on either side of the existing road. Buffer zones were created and the villages falling in the intersection of these two buffer zones were identified as the target villages for the implementation of biogas plants.
- *Step 7.* Using the fraction of households (f_i), the target potential of biogas plants was calculated (Table 4). The estimated potential of the biogas plants is 600 Khimiyang and Vijoynagar circles have very low potential, as a result of which they have been excluded from the initial phase of the plan.

TABLE 4
Identified and target potential (1996–2002)
of the biogas plan

Block	Identified potential	Target potential
Bordumsa	700	100
Changlang	100	20
Diyun	700	250
Khimiyang	20	—
Manmao	30	10
Miao	600	200
Nampong	30	20
Vijoynagar	20	—
Total potential	—	600

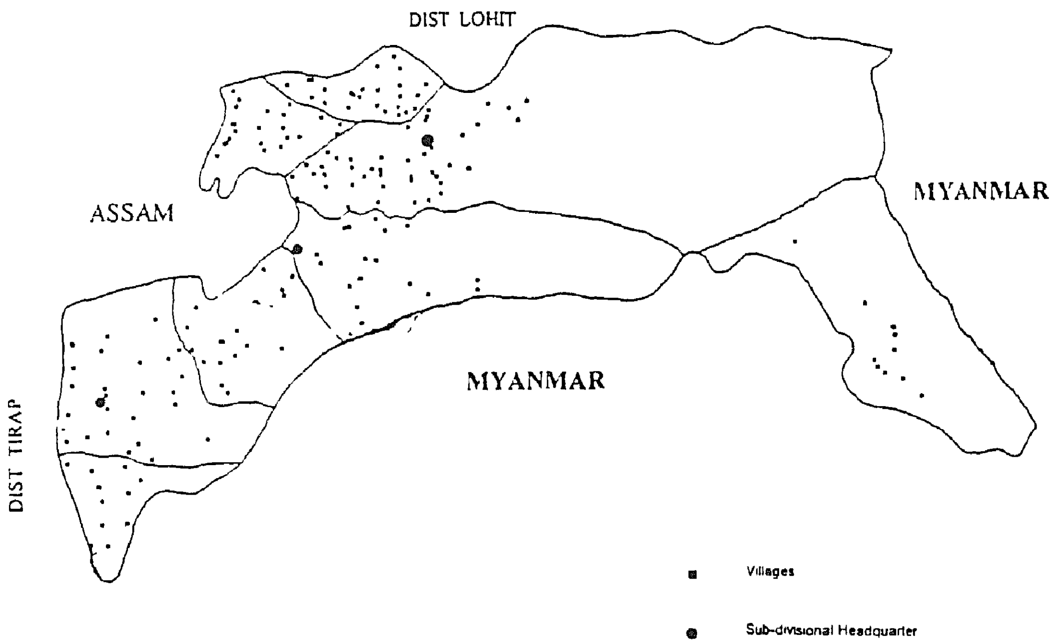
Biogas: what needs to be done?

The most important factor for the effective implementation of the technologies like biogas plants is the acceptability of each technologies by the people. In the plains (Bordumsa, Miao, and Diyun), there is very high potential for biogas plants as the cattle holdings are higher, and, in addition to this, these areas are agriculturally prosperous, and groundwater potential is very good. Whereas, in the hilly areas of the district, cattle rearing practices are different, and most of the area is a run-off water zone, hence, availability of water and dung is low. Since households in the district have been using dung as farm manure only, a shift in its use to an energy source would require awareness creation. As the livestock information is available only at the circle level, detailed feasibility studies need to be done in all the villages identified in the present plan to arrive at the actual number of biogas plants to be installed in each of these villages. Apart from the *Deenbandhu* model, another model *Swastik* (portable; made of special rubber) can be implemented in the district However, field testing of this model would be required.

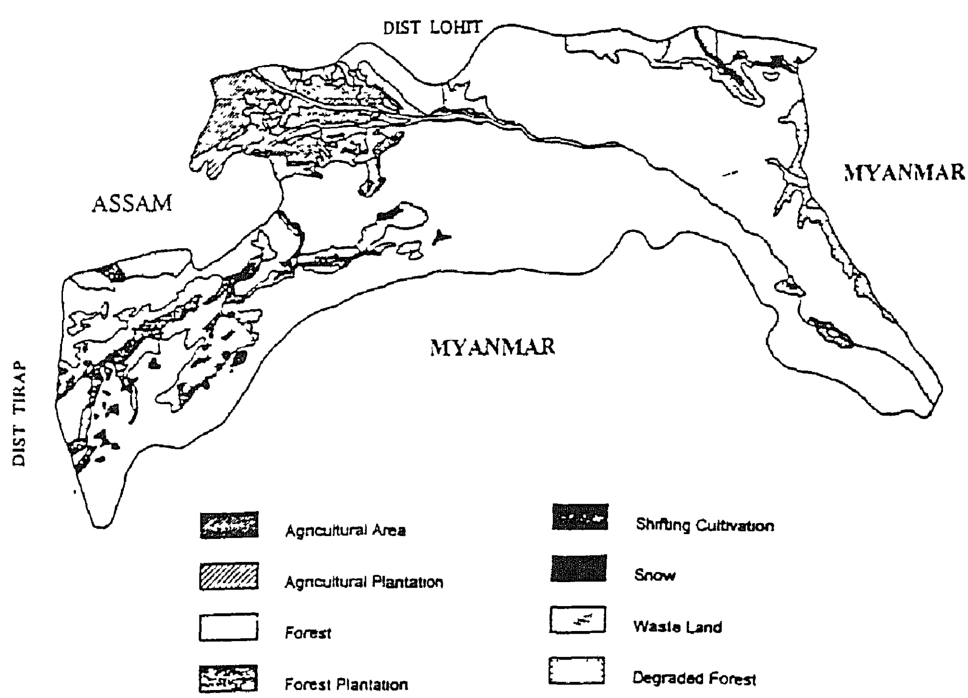
Conclusion

Dissemination of ICs and biogas plants in the district requires awareness among the villagers, as this intervention would have a direct impact on their living style, cooking habits, and social life Thus, one of the key aspects of the plan has been to first create awareness among the villagers of its benefits in the context of the fast denudation of their forest and its environmental impact Furthermore, the type of ICs recommended for the region are not field tested, and these should be initially tested in the field and modified as per the needs of the end-users.

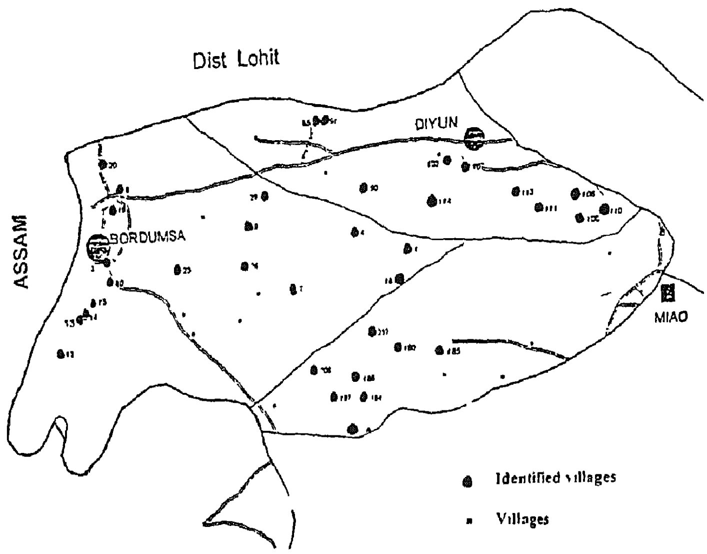
One of the major limitations of this plan has been the inability to clearly identify the areas and the number of these devices to be installed, even after the use of a powerful tool like GIS. Two other major constraints have been the non-availability of topographic sheets and the lack of land information. As the entire north-eastern region is considered to be sensitive, topographic sheets of these regions are not available. One of the major advantages of having a topographic sheet would have been the access to much more detailed information about biomass resources availability. Planning for biomass resources, therefore, would especially have been much better



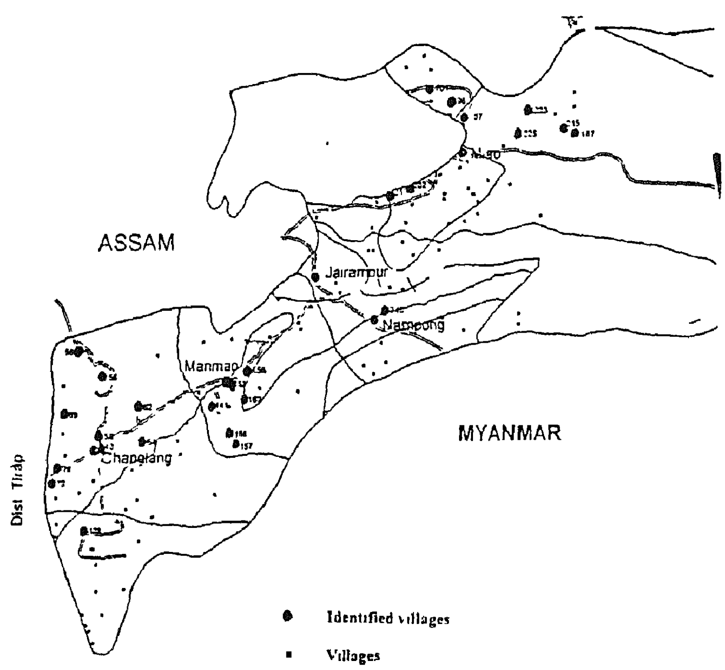
Map 1. Village map
Base map for developing the intervention plan, which was superimposed on other coverages to identify the target potential of IC and biogas plants



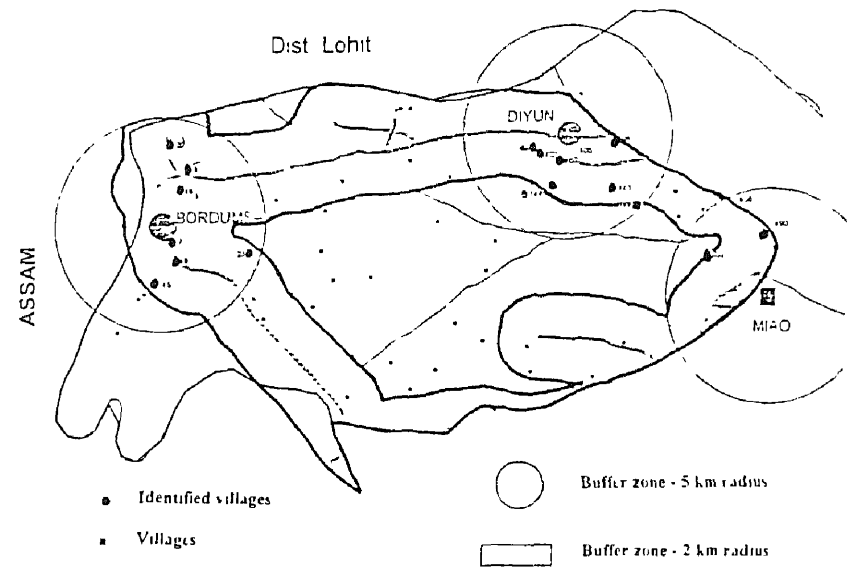
Map 2. Land map
This map depicts the land-use pattern in the district. The village map was superimposed on this map to identify the villages where intervention plan can be implemented



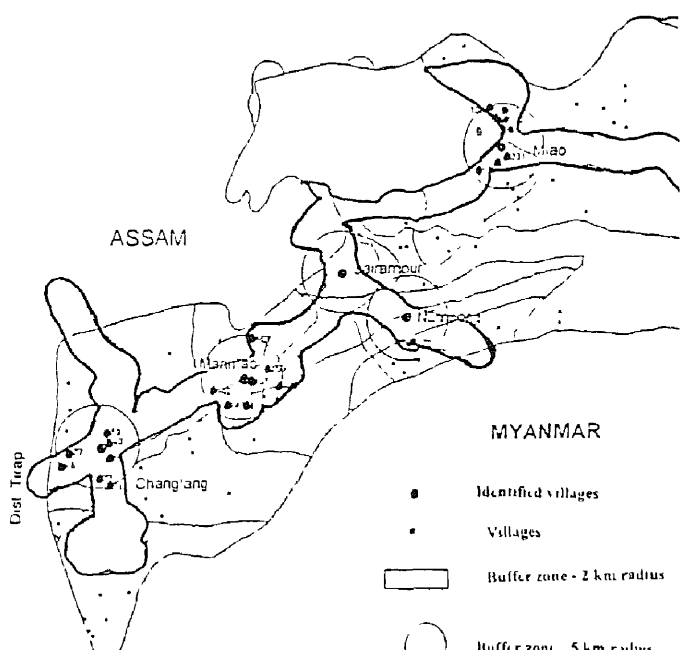
Map 3. IC plan – Bordumsa, Miao, and Diyun
The village map was superimposed on the land-use map and the villages in the settled agricultural areas was identified. Using the preference rate, the target potential of ICs in these villages was obtained



Map 4. IC plan – hilly areas
The village map was superimposed on the land-use map and the villages in the degraded forest land and shifting cultivation area. Using the preference rate, target potential of ICs in these villages was obtained



Map 5. Biogas plan – Bordumsa, Miao, and Diyun
The village map was superimposed on the land use map. Buffer zones (intersection of 5 km radius from circle headquarters and 2 km radius of existing road) were created to identify the target potential of biogas plants



Map 6. Biogas plan – hilly areas
The village map was superimposed on the land use map. Buffer zones (intersection of 5 km radius from circle headquarters and 2 km radius of existing road) were created to identify the target potential of biogas plants

COPING WITH BIOMASS SCARCITY: A VILLAGE CASE STUDY

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Background

It is well recognized that India today faces an environmental crisis of serious dimensions. India's population exceeds 850 million and is expected to cross the one billion mark by the turn of the century. Today, natural resources such as forests, pasture lands and unculturable wastelands, despite their state of degradation, meet the subsistence needs of millions of people living in rural India, most of them landless or poor marginal farmers. The forests as a form of natural resource are particularly under severe stress. The forest cover in India has reduced from 33% of the total area in 1947 to 19% by 1995 This deteriorating situation has several consequences as forests play an important role in preventing water run-off, aiding soil conservation, supply of various forest produce, acting as carbon sinks, etc Scarcity of water has become a major issue all over the country, especially in the ecologically fragile areas (Mukherjee 1994)

Deforestation and degradation takes place mainly due to commercial and industrial demand, expansion of agricultural land into forest areas, and needs of fuel, fodder, and other produce As a result of an increase in human activities, nature's regenerative capacity has failed to keep pace with the level of resource extraction and its consequent impacts In the past, the traditional ecological prudence of the people, supplemented by moderate and controlled demand on natural resources, helped in sustaining them for generations However, this balance has dramatically changed during the last few decades owing mostly to inequitable distribution of income, escalating demands, ineffective management practices, and growing population Inequalities in access rights over the resource base, and the ways

in which they are used, are equally important in determining the sustainability of the resource.

The deteriorating status of natural resources has had important ramifications for the people and for the economy and society of the rural areas. With the depletion of natural resources, livelihood sustenance has become difficult, thereby forcing migration to urban areas in search of alternative employment opportunities. As a direct consequence of depleting resources, the rural women have to spend more time and travel longer distances for the collection of fuel, fodder, and water (Agarwal 1986). This additional burden also cuts into the time that a woman devotes looking after children and other household chores. Inefficient cooking devices, coupled with the use of inferior fuels like shrubs, crop residues, animal dung, weeds, etc., lead to smoky kitchen environments which has deleterious impacts on the health of the users (Kirk 1993) In many parts of the country, women have taken to headloading (sale of wood collected from the forest, in neighbouring towns and villages) as an alternative means of earning money required to supplement the household's food, fodder, and fuel requirements. These interactions among demographic and environmental factors render the population–natural resource linkages rather complex and highly variable over time and space.

In order to cope with resource degradation, local communities have adopted different strategies having region-specific variations. These include informal resource management systems like the forest protection committees in the tribal belt of Orissa where people are dependent on various types of forest produce for their daily livelihood sustenance, the protection of *Khejri* trees by the *Bisnoi* community in Rajasthan, etc. On the other hand, in areas of severe resource degradation, like in Chota Udaipur and Gujarat, women have shifted to inferior fuels like weeds and shrubs for meeting domestic energy needs. There have also been several instances in different parts of rural India, of encroachment on forest land for agricultural purposes, migration (primarily of the men-folk) to peri-urban and urban areas in search of employment, etc. In contrast to these local strategies, over the last few decades, there have been several interventions by the government through various policy measures for natural resource management. While some of these measures like the Social Forestry Programme, wasteland development, fuelwood plantations, etc., attempted to enhance the supply of resources, others looked at conservation of resources by improving energy efficiency or substituting the fuelwood use like the National Project on Biogas Development, the National Programme for Improved *Chulhas* (cookstoves)/Solar cookers, etc. However, most of the formal conservation attempts and other interventions have not achieved much success due to the growing demands of an increasing population, inappropriate and inequitable development programmes, and lack of people's involvement, and especially of women, in planning and decision-making.

The nature and type of coping strategies are location-specific and depend on a variety of factors like the extent of degradation, ownership of the resource, existence of grassroots organizations, and, most importantly, the degree of people's dependence on these However, there is very little documentation, and even less dissemination, of this traditional knowledge, which could provide useful insights for developing effective management systems.

Introduction

With the above background in mind, TERI took up a research project which aimed to fulfill the knowledge gap that exists regarding the impact of resource degradation on local village communities and the coping strategies adopted by people to manage this. In order to capture the variations across agro-climatic regions, in terms of ecological degradation and the consequent strategies adopted by local communities, three case studies were undertaken in 1995. One of them, was in the central Himalayan region of the Kumaon hills.

The central Himalaya covers an area of about 51 000 km^2, bordering Tibet in the north and Nepal in the east This part of the Himalaya, which lies in Uttar Pradesh (UP), is divided into Kumaon and Garhwal divisions. The Kumaon division comprises the districts of Almora, Nainital, and Pithoragarh.

The Kumaon hills are characterized by dense alpine vegetation. A harmonious relationship existed between the people and natural resources. The livelihood system of the rural populace has been intricately linked with the forest ecosystem of the region by way of providing fuelwood, dry leaves, and green fodder, timber for local housing, and wood for agricultural implements Agricultural production is closely linked to forests, the fertility of the land being maintained by dung from livestock and by leaf compost. However, these forests also have excellent commercial value for the available timber, and this has been exploited considerably for supplies to the railway, and to match and paper, sports goods, and furniture industries. While governmental policies have not been very conducive to reversing this phenomenon, rapid population increase added to the resource degradation in the region. The communities living in these areas, who are completely dependent on these resources for their daily livelihood sustenance, are finding it increasingly difficult to continue with a sustainable lifestyle. While men try to migrate to the plains in search of employment, the women have to take up the entire responsibility of household sustenance in the villages

The objective of the present study was to assess the existing stress on biomass resources (including forest and non-forest lands) as against its usage for domestic energy and non-energy purposes, and, thereby, determine the extent of its degradation and the resultant impacts It also identifies the resource management efforts and strategies adopted by people, particularly women, at both the formal and informal levels to manage biomass resource degradation The *van panchayat* (VP) forests developed by village communities on degraded land have been studied as one of the formal intervention strategies that has been taken up to deal with the energy crisis. The study reflects the socio-economic impact of these coping strategies as well.

The study

This paper, therefore, presents a micro-level case study of the interface between natural resources and local communities and the ramifications of environmental degradation on the rural communities living in close proximity to these resources A case study was carried out in the village Dhankalgaon situated in the Ranikhet *tehsil* of Almora district during the

summer of 1995. This village was selected as a representative unit of the Central Himalayan region, in consultation with Pan Himalayan Grassroots, a local non-governmental organization.

Methodology

In order to reflect the micro-level strategies for natural resource management, the case study method of analysis has been used for this study. The field research included participatory rural appraisal techniques like resource mapping, social mapping, time line, seasonality, and time budgeting exercises for information collection. Structured questionnaires have also been used for data on resource availability and energy consumption at the household level.

The village

Dhankalgaon village is a typical village of the Kumaon hills of the Central Himalayan region. It is a small village located at an altitude of 1140 m, about 25 km north of Ranikhet town, in the Gagas river watershed.

The village is primarily dominated by the upper caste Brahmin; the scheduled caste, *Shilpakar*, accounts for 30% of the village population (Table 1). Out of the total 72 households in the village, 6 families have permanently migrated to other parts of the country. The village, with a total geographical area of 55.877 hectares (ha), is situated along the left bank of the Gagas river and is spread over five hamlets (*toks*). The village is electrified, though electrification is restricted to only about 29% of the households.

The history of Dhankalgaon dates back to over 500 years when the first Brahmin family of Guran Joshi migrated from Almora town to this part of the Dwarhat block along with a *Shilpakar* family. Prior to 1950, ownership of all private agricultural land vested with the

TABLE 1
Profile of Dhankalgaon village

Gram panchayat	*Chiali*
Number of households	66
Population	400
Castes	*Brahmin*, *Shilpakar* (scheduled caste)
Major crops	*Kharif*: Rice, *maduwa*, maize, pulses *Rabi*: wheat, *jau*, *jowar*, *rai*, mustard
Livestock	167
Total land area (ha)	55.877
Village forest (ha)	8 024
Agricultural land (irrigated) (ha)	33.156
Agricultural land (unirrigated) (ha)	4.463
Culturable wasteland (ha)	4.369
Unculturable wasteland (ha)	5.838
Primary school	Dhankalgaon (0 km)
Middle school	Bhogwalipokhar (2 km)
High school	Chanagolu (3 km)
Primary Health Centre (PHC)	Bhogwalipokhar (2 km), Chanagolu (3 km)

Brahmin. The scheduled caste families, while being landless, were entirely dependent on the Brahmin households for their daily subsistence, thereby forging a patron–client relationship between the two communities. The Brahmin families were primarily agricultural households with no wage labour income.

Lifestyle changes

Today, not much has changed in terms of the social stratification, as the *Shilpakar* families are still considered untouchable and have a separate drinking water source. However, with time, changes have taken place in terms of the economic status of both the communities, which, in turn, has brought about changes in the rural household livelihoods and economies. Today, most of the scheduled caste families own small pieces of land, which, though marginal in quality, at least meets a part of their annual food requirements In a general sense, the upper castes in the village are much better off primarily because they own more and better quality land in the valley areas suitable for the cultivation of paddy. While the maximum land owned by a scheduled caste farmer in the village is about 1 acre, 57% of the Brahmin families own more than 1 5 acres of land, the maximum of 3 15 acres being owned by the *sarpanch* (head) of the village

An increased family size has brought about land fragmentation. Also, over the years the land quality has deteriorated due to neglect, lack of adequate water resources, and over-exploitation, resulting in reduced agricultural productivity. Non-remunerative agriculture and lack of local employment opportunities has resulted in migration of the male population to the plains in search of work, leaving behind the women to take care of all the agricultural operations. This need for employment outside the village for supplementing household income has increased the value of formal school education among the villagers. Consequently, today, all children, both male and female, belonging to both the castes are being sent to school. Some of the educated scheduled caste men and women have taken advantage of the government schemes for backward and scheduled caste communities and obtained positions in schools and other government services in the hills.

Socio-economic status

Agriculture is the primary occupation of all villagers of Dhankalgaon. Other means of occupation like employment in private or defence services for the educated menfolk and wage labour for the rest of the people, are important means of secondary income It was observed that only 19% of the families were entirely village based, which means agriculture is their primary occupation, while wage labour supplements their household income.

Though agriculture is the primary occupation of the residents of Dhankalgaon, yet it is completely rainfed and practised at a subsistence level only. The *Gagas Pariyojana*, an irrigation canal constructed in 1950 and to which the village is a beneficiary, provides erratic and inadequate water supply to the farmers of this area. As a result, though the revenue settlement records of the block indicate 88% of agricultural land as irrigated, in reality, the absence of water enables the production of only one crop a year, thereby reducing incomes from agriculture drastically. Food production just about meets the consumption requirements of the family, and does not have any provisions for sale in the open market. Rice, *maduwa* (ragi), *makai* (maize), and a few varieties of pulses are the primary *kharif* crops.

Some farmers cultivate wheat, *jau* (barley), *jowar* (sorghum), *rai* (rapeseed), and *sarson* (mustard) in the lower valley areas, during the winter season. Rice is the main crop in terms of area and productivity.

The livestock population of the village is 167, comprising cows, bullocks, and buffaloes, which implies an average cattlehead of 2.3 per family The livestock is maintained primarily to meet the draught power Animal dung is an important source of domestic fuel in addition to its use as organic manure in the agricultural fields There are a very few number of milch cattle, and the milk available is utilized entirely for domestic consumption.

Resource base

The biomass resource base of the village includes private agricultural land, the village forest, and parts of the unculturable and culturable wastelands Out of a total geographical area of 55 877 ha, private agricultural land accounts for 60% of the land area of the village. Fresh green grass collected from the *bheeta*[1] land between July and September is the only source of green fodder for the livestock. *Mehul* (*Pyrus patia*) trees, the prominent grafting stock for Pear, dominating the agricultural field bunds, yield dry twigs and branches for fuel, leaves for fodder, and fruits. In addition to the agricultural fields, every household in the village has a homestead varying in size from 0.5 to 1 *nali*[2] These homesteads have a thick vegetative cover of fruit trees like peaches, plums, and pomegranates, fodder and timber trees like *Bakain* (*Melia azedarach*), *Kharik* (*Celtis australis*), *Toon* (*Cedrela toona*), and *Beul* (*Grewia optiva*). Some families also manage to grow small quantities of vegetables in the homesteads.

The Eiradeo Reserve Forest (RF), under Someshwar range of the UP Forest Department is situated 10 km from Dhankalgaon. This forest was the primary source of domestic energy needs in the past, and still continues to be for 132 other neighbouring villages. As per the register for disbursement of timber rights (Forest Department, UP), Eiradeo forest has 2509 4 ha and 2310.4 ha under *Chir* and *Banj* tree species, respectively The Dhankalgaon village is allowed to harvest less than one per cent of the sustainable yield. The villagers have traditional usufructuary rights over this forest, which includes dry and fallen twigs and branches, dead trees, leaves, *Pirul*[3] (*pine* needles), grass, and fruits. They also have a right to timber for house construction, obtainable on the basis of a permit issued by the Forest Department. However, due to non-availability of adequate drywood, the women have resorted to illegal felling of green trees to meet their cooking and heating needs. Even the wood purchased by the villagers comes from this RF.

The culturable and unculturable wastelands together form the *Civil Benap Land* of the village which is primarily utilized as pasturelands. This land was used for open grazing the village livestock till parts of it were enclosed in 1958, for afforestation activities by the villagers, and by several government departments like the Soil Conservation Department, the Block Office, and the *Gagas Pariyojana*. A village level committee called the *Van Panchayat Samiti* (VPS) is responsible for managing 8.024 ha of community plantations.

[1] *Bheeta* land is the vertical land between two successive agricultural fields

[2] *Nali* is a unit of land measurement 20 *nalis* = 1 acre

[3] *Pirul* is the local name for pine leaves which look like needles

Apart from fuelwood, today, this area has become an important and easily accessible source of grass (used as dry fodder) and *Pirul.*

Biomass system

The biomass system of a village is determined by the people's allowable access to various biomass sources, which is dependent on the rights and concessions over biomass extraction The villagers of Dhankalgaon have the rights over the biomass growing on their agricultural fields (crops, residues, grasses, and shrubs), and have a concession over common biomass resources (village forest, village common land, and nearby reserve forests).

The energy system

Fuelwood has been the traditional and primary fuel utilized for domestic cooking and water and space heating in villages in the fields of the central Himalaya. However, with the gradual degradation of the forest resource base in the vicinity of the village, the fuelwood requirements were being substituted by inferior fuels like dungcakes and shrub-wood. To that extent, one can say that the energy system is a subset of the biomass system of the village. Even today, biomass is an essential and necessary ingredient of the domestic energy system of Dhankalgaon, while a very small portion of this need is being fulfilled by commercial fuels like kerosene and liquefied petroleum gas (LPG).

Cooking and heating

Fuel requirements for these activities are being met either through collection or by purchase of biomass fuels, like wood and dungcakes, and, in a few cases, through commercial fuels too. Fuelwood, in the form of dry twigs, branches or logs, from trees and shrubs is the primary source of cooking and heating energy for all 66 households. The consumption of fuelwood almost doubles during the winter months due to the need for space heating. The average consumption of wood works out to be 2 28 kg per capita per day. While the popular fuelwood species are *Banj* and *Buransh*, the present wood types used as fuel include *Chir*, *Mehul*, *Kaphaal*, *Banj*, and *Buransh* Apart from *Mehul*, which is available from the homesteads or from the agricultural field-bunds, all other types of wood are normally collected from the Eiradeo RF or purchased from the neighbouring villages.

Fuelwood is collected from the Eiradeo RF either by the female members of the households or by hired labourers. Fuelwood is collected almost everyday during the four winter months (mid-November to mid-March) and stored for consumption throughout the year In the summer and monsoon months, wood is collected only in case of emergencies and that too from the privately owned trees. Wood is also purchased from the local market or from the neighbouring villages at the rate of Rs 30 for a bundle weighing 25–30 kg. Similar amounts have to be spent on hiring labourers for fuel collection. Within the upper caste community in the village, 34% of the households depend entirely on purchased fuelwood, 33% use wood only collected from various sources, the remaining 33% of the households use fuelwood obtained by both means Among the scheduled caste households, however, 83% depend on wood gathered from various private and community lands owing to their poor economic status, while the balance 17% purchase wood from the market The various sources of fuelwood for all households in the village has been shown in Figure 1.

Shrubs share a major part of the fuelwood supply. A substantial part of the shrub biomass comes from the Eiradeo forest, particularly from the *Banj* canopy. In addition to the above source, due to the ease in availability, dry twigs and branches are also collected from shrubs like *Kilmora, Ghingaroo,* and *Hissaloo*, growing in the homesteads or on the unculturable wastelands of the village.

Till the beginning of the 1990s, animal dung mixed with the *Pirul* was utilized solely as organic manure in the agricultural fields. But, today, dungcakes are increasingly becoming a fuel option for domestic energy requirements. Dungcakes are used as a cooking fuel in summers and as a heating fuel in the winter months. They are also used for heating (space and water) by 51% of the families (Table 2). On an average, 1.57 kg of dungcakes are being consumed as fuel daily. While 70% of the Brahmin households are using dung for heating and cooking, its use within the scheduled caste community is limited to only about 17% of the households and that too for only water and space heating. Apart from a few exceptions, most of the scheduled caste households own one or two cattle-heads, and, hence, whatever dung is available is usually collected and stored for manure purposes. Dung for fuel is collected from the community grazing and wastelands.

Biogas has been recently introduced in the village by a local non-governmental organization as an alternative source of cooking energy At present, only two biogas plants have been installed in the village on a demonstration basis. While one of the plants is working efficiently and meets the complete cooking fuel needs of the family, the other plant works only intermittently due to a defective part. The difficulties in water availability and collection, coupled with an irregular maintenance system, is the principle reason for the limited spread of this technology in the village.

Commercial fuels like kerosene and LPG have become popular within the economically better-off households of both the upper and scheduled castes During the rainy season, kerosene is an important cooking fuel. 50% of the households use kerosene regularly for cooking. At present, eight per cent of the families have LPG connections, while many more are awaiting new connections

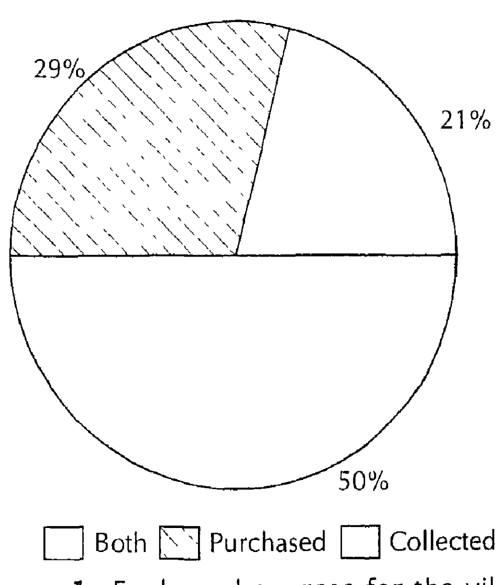


Figure 1. Fuelwood sources for the village

Table 2
Household distribution of fuel-mix for various end uses

Type of fuel	Number of households using fuel (end use-wise)					
	Cooking		Water and space heating		Lighting	
	SC	Brahmin	SC	Brahmin	SC	Brahmin
Fuelwood (logs and shrubs)	23 (100)	43 (100)	23 (100)	34 (79)	—	—
Dungcakes	—	31 (72)	4 (17)	30 (70)	—	—
Kerosene	11 (49)	22 (51)	—	—	23 (100)	43 (100)
LPG	1 (4)	4 (9)	—	—	—	—
Biogas	—	2 (5)	—	—	—	—
Electricity	—	—	—	—	5 (22)	14 (33)

Note. The figures in brackets indicate percentages.

Lighting

The village is electrified. However, only 29% of the households have reported electricity connections of which, 74% belong to the upper caste. But the erratic power supply, and especially its absence at night, compels them to rely primarily on kerosene for meeting their lighting needs; all the households use it as a source of light. The monthly consumption of kerosene varies from 1 to 4 litres per month. Kerosene purchased from the Fair Price Shop does not suffice and has to be purchased additionally at higher prices from the open market The village does not have any electric or diesel pumpsets for irrigation purposes.

Fodder

At present, no fodder crops are being cultivated specially in the village due to inadequate irrigation facilities Crop residue and grass collected from common lands are used as fodder Crop residues like rice and wheat stalks form the major portion of the fodder-mix. In addition, grass is used to supplement the daily feed. Fresh grass from agricultural field bunds and crop-weeds are collected during the monsoon months (July–September). During the months of November–December, the VPS of the village keeps the enclosed areas open for the harvest of dry grass for five days. This dry grass or *lutya* is stored for usage during winter and summer seasons. Leaves from fodder trees like *Mehul, Betan, Bhimal, Bhikua*, and *Khadig* are mixed with the crop residue to provide additional nutrition. A cereal mix crushed into a paste is also fed to the milch cattle or to the bullocks during the ploughing season. The per capita per day fodder consumption is about 6 kg.

Non-energy end uses

The other non-energy end uses of biomass include rope-making, house construction, and furniture Timber for construction purposes is either collected from the Eiradeo RF

through a permit, or purchased from the market. The villagers have enjoyed timber rights for domestic use against payment of royalties to the Forest Department But, for the last few years, such concessions have not been granted, and the villagers meet their requirements from the market. Medicinal plants, whenever available, are also collected from the RF for personal consumption

Biomass-based livelihood system

A livelihood system implies a dynamic process by which 'rural households rearrange over time their mix of resources and activities to cope with changing economic and social objectives or contingencies' (Laurie 1995). Similarly, the villagers of Dhankalgaon have had an intricate relationship with its immediate natural environment like the forest, the livestock, and the agricultural land for their daily livelihood sustenance. However, this traditional livelihood system is no longer able to sustain the needs of the villagers, and has, therefore, gone through a process of change to keep pace with the dynamic external environment. Today, the market plays an extremely important role in this livelihood system as the dependence on the market for food, fuel, and employment has increased tremendously This case study also highlights the multiple activities and sources of food, income, and security that the livelihood system of the poor area is based upon The livelihood system of the people of Dhankalgaon and the interlinkages between each of the subsystems have been depicted in Figure 2

Women play a key role in this livelihood sustenance system All women collect fuelwood from the community (RF and unculturable wastelands) and private lands for cooking, and water and space heating requirements. The sale of fuelwood as headloads has become a source of income for many women living in the vicinity of the Eiradeo RF. Timber for construction purposes is either collected from the RF through a permit or purchased from the market. In the households with cattle, women collect forest products like *Pirul* and grass. *Pirul* is used initially as livestock bedding, which is finally composted with the animal dung to make biofertilizers used in the agricultural fields Agriculture in Dhankalgaon has not been mechanized and bullocks are still utilized as draught power. These agricultural lands besides providing food for the people also produce weeds and crop residue as fodder for the cattle and fuel in the form of the branches of the trees growing on the field bunds Each of these biomass extraction activities, necessary to sustain life, are performed at different times of the year from different biomass systems. A diagram indicating the seasonality in biomass resource use and collection has been given in Annexure 1. The market is an essential source of income necessary for substantiating the resources available from the village biomass resource base.

The importance of forests in the village livelihood systems is very apparent from the variety of biomass derived from the resource and their multifarious utilities. However, unrestricted harvesting of biomass will cause severe stress on the existing resources resulting in their gradual depletion. The annual demand and supply for biomass to meet the domestic energy and fodder demands has been summarized in Table 3

The above table gives an indication of the extent of stress that has been taking place on the resource base of Dhankalgaon in terms of the annual extraction of biomass resources. While the availability of animal dung for fuel purposes and of fodder far exceeds the

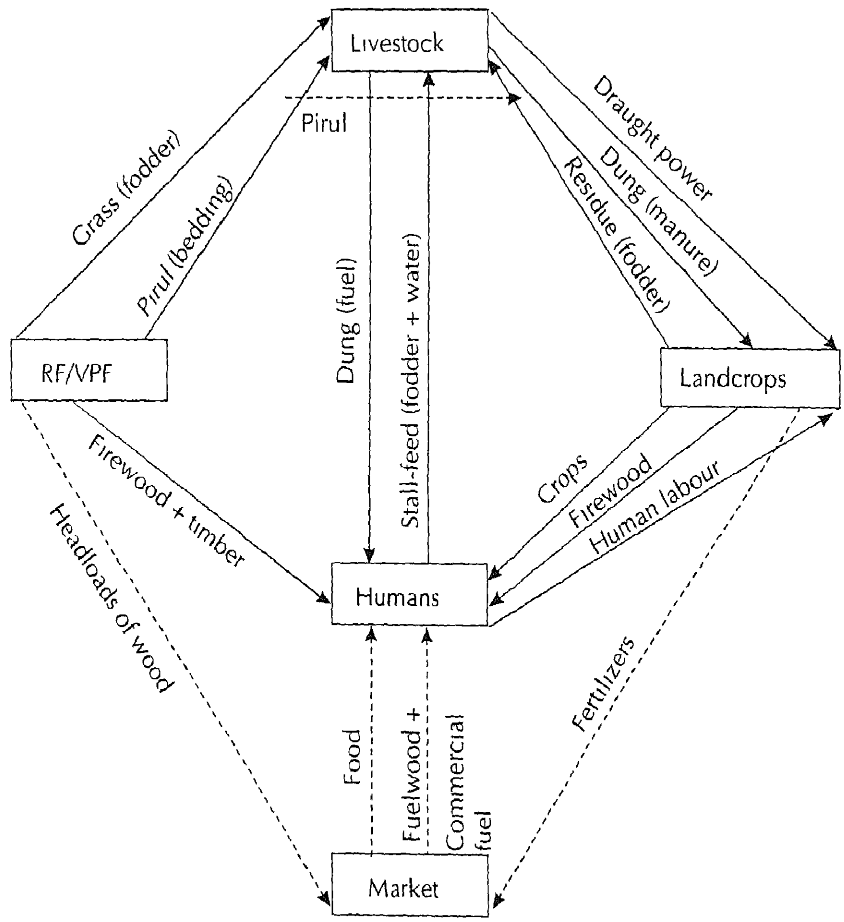


Figure 2. Biomass-based livelihood system

TABLE 3
Annual biomass supply and demand in the village (tonnes)

Biomass	Supply	End use	Total supply	Consumption
Dung	65.830	Cooking	65.830	22.40
Crop residue	390.478	Fodder	520.811	365.73
Grass (settlement)	56.910	Fodder	—	—
Grass (village)	73.423	Fodder	—	—
Shrub (village)	42.830	Cooking	114.110	340.00
Shrub (settlement)	30.566	Cooking	—	—
Scattered tree (village)	26.345	Cooking	—	—
Tree canopy (village)	14.370			

present consumption patterns, the situation is particularly alarming in the case of the supply and demand of fuelwood. Dungcakes for cooking are prepared out of the total daily collectible dung, and, hence, are consumed at the cost of its alternative use as organic

manure in the agricultural fields. Enclosure of the once barren community land for afforestation prevented open grazing, and helped in the regeneration of grasses which have fodder usages. These dry grasses, along with the crop residues have helped to alleviate the fodder crisis substantially. However, the domestic fuel crisis continues unabated. The demand for fuelwood is more than double the supply from the local Eiradeo RF, the primary source of fuelwood

Response strategies

The strategies adopted by the households to deal with the resultant resource degradation varied with individuals, households, and communities across the villages. These are adopted by the vulnerable sections to minimize the risk in their lives and to incorporate changes in their livelihood systems. These strategies are 'usually diverse and often complex' and the patterns of diversification may evolve over a long period of time through trial and error and not necessarily only with the economic ends in view (Laurie 1995)

In Dhankalgaon, most of the coping strategies adopted by the people have been devised at the household level. At the community level, the VP managed plantations are the only attempt made by the people to alleviate the status of resource degradation.

Van panchayat

At the village community level, an important formal intervention has been a plantation on 8 ha of revenue land in 1958, under the aegis of the VPS. Recognizing the fuel shortage faced by women in the village, the barren and degraded Civil Benap Land was enclosed for regeneration and protection of grass and *chir* trees, planted by the villagers. Subsequently, six other plantations were made in the 90s by various government departments on degraded community land in the village. *Chir* and *Acacia* species of trees are most commonly found in all the plantation areas, while one patch has some trees of *Betan* and *Shahtoot* (*Morus alba*) variety.

A village level committee (VPS), comprising seven male members, is primarily responsible for all decisions related to this *van panchayat* forest (VPF). All the resident households of Dhankalgaon are *ipso facto* members of the VP and are entitled to all the benefits accruing from the resources managed by the body Though women have not been appointed as members of the committee, they support the efforts made in regenerating the degraded land No illegal felling of trees, lopping, and grazing is permitted inside the enclosed area. A *chowkidar* appointed by the VP protects the enclosed area during the monsoon season from grazing.

In spite of the fact that the fuelwood crisis was the primary reason for developing the plantations, at present, the villagers do not get any fuelwood from these protected areas Only fodder and bedding requirements of the village livestock are being met to a considerable extent The close proximity of these areas to the settlements has relatively reduced the burden of the women in terms of fodder collection for the stall-fed livestock The afforested area is kept open twice a year A grass and *Pirul* distribution system was devised by the VP committee to ensure equitable access to the common resource, wherein one member from each family is allowed to collect the same from the enclosed area Grass is collectively harvested by all the villagers for five days in a year between November and

December, and *Pirul* for four days in May during which each household is allowed to collect twice a day. Till last year, the villagers were entitled to collect stones for house repair and construction from the VPF, which has, however, been stopped by the district authorities.

Fuel substitution

The pressure of an increasing population has taken a heavy toll on the Eiradeo forest, and both the availability and the quality of wood available for meeting domestic cooking and heating needs have reduced drastically. Good quality wood like *Banj* and *Buransh* has almost become extinct in this forest and can be purchased from the market only by the rich. As a result, there has been a conscious shift towards the use of inferior wood like *Chir* and *Mehul*. Lopping trees growing on individual homesteads or agricultural land for fuelwood and fodder have become an option for those households who possess these individual resources. For the scheduled caste families in the village, who have very small land holdings, the dependence on the government forest still continues. Not only are these resources far away, they are also scarce.

The flow of cash incomes from the plains has enabled many families within the village to purchase quality wood from the market or to shift to commercial fuels like kerosene and LPG. Consequently, a considerable part of their monthly income is being spent on fuel. About 30% of the women have started purchasing fuelwood, more than 80% of whom are *Brahmins*. Commercial fuels like kerosene and LPG have become important alternatives to the traditional but scarce biomass fuels. At present, these commercial fuels do not completely replace biomass fuels as the availability is limited. However, it was observed that while a family dependent entirely on wood spent at least five days per week on wood collection, a family using LPG/biogas had to spend only two days per week. In these cases, again, migration has reduced the working hands available within the family to share the various household chores. Hence, many women have shifted to the use of inferior fuels like shrubs and dungcakes, which involve lesser collection time and effort. Nearly 33% of the collectible dung is being diverted from manure to dungcakes.

Biogas plants

The installation of biogas plants in the village by two families with the help of a non-governmental organization is a step towards managing the biomass fuel scarcity. Both these families have the resources required for installing biogas plants, which include adequate number of livestock and easy access to water. The use of biogas as fuel has reduced the workload of the women in both households to a considerable degree, in terms of the fuelwood collection and cooking time There is, therefore, more time for agricultural activities and for relaxation.

Diversification of activities

Although primarily agriculturists, many households participate in at least two or three secondary activities for supplementing the household income. Robert Chambers (1994:17) describes this adaptive strategy as a diversified portfolio of activities (Laurie 1995):

with different members of the family seeking and finding different sources of food, fuel, animal fodder, cash and support in different ways in different places at different times of the year Their living is improvised and sustained through their livelihood capabilities, through tangible assets in the form of stores and resources, and through intangible assets in the form of claims and access

Table 4 shows the diverse activities and sources of household inputs of five selected representative households of Dhankalgaon, belonging to both caste groups. While the first two households are from the scheduled caste *Shilpakar basti*, the other three families belong to the upper caste. Except Household 2 (HH2), all other households have access to food, fuel, and fodder from their own resources. In the case of Household 2, as the couple have government jobs, they have little time for agricultural activities, thereby depending on the market for all household inputs While their share of the agricultural land is tilled by their brother, the family owns no livestock and commercial fuels like kerosene and LPG and fuelwood purchased from the market are used for cooking and heating purposes. While wage labour is a secondary source of employment for the poorer scheduled caste household (HH1), employment outside the village in government and private organizations bring income for Households 2, 3, and 4. Ecological destruction has eroded the resource base on which the livelihood system of the people of Dhankalgaon was based but a diversification of activities helps in reducing the risk in depending on one source of livelihood All individuals in a household are involved in livelihood sustenance in some way or the

TABLE 4
Diversification of activities

Particulars	HH1	HH2	HH3	HH4	HH5
Non-market household inputs					
Food from crops	√		√	√	√
Milk	—		√	√	—
Fodder	—		√	√	√
Fuel	√		—	√	√
Biogas	—		—	√	—
Market household inputs					
Milk	—	√	—	—	—
Fuel					
Commercial	—	√	—	—	√
Biomass	—	√	√	√	—
Food	√	√	—	—	—
Agricultural inputs	√	—	—	√	√
Income generation through employment					
Employment in government	—	√ (2)	—	√	—
Employment in private organizations	—	—	√ (3)	—	—
Seasonal agricultural labour	√	—	—	—	—
Other jobs in the village[a]	√	—	—	—	—
Others[b]	—	—	√	—	—

[a] 'Other jobs in the village' include wage labour as construction labourers; [b] 'Others' include work like that of the *Gram Pradhan* or *Sarpanch* (village head).

other, while the women take care of the domestic well-being including the production of food, fodder, and fuel, the men take care of the cash earnings required for purchases from the market.

Migration is a very prominent strategy that the men have adopted to bring in additional income. The men migrate to towns and cities in the plains even if they do not have a permanent job. Income from the plains is the only source of cash earnings, which is important for living in an economy that is increasingly dependant on the market for subsistence. A higher education level within the *Brahmin* families has also contributed to an increased incidence of migration in this community, where a number of male members are working in places as far away as Abu Dhabi and Dubai.

The unskilled and uneducated scheduled caste families have resorted to wage labour, either agricultural or construction, as a secondary source of income. There are incidences of seasonal migration of labour to the nearby towns and to the villages located near the plains to work as agricultural labourers primarily during the *Rabi* season.

Manifestations of the coping strategies

The strategies adopted by the village community have been developed over a period of time. Also, it is important to note that there is no one specific coping strategy for a particular problem but a bundle of options. These options are not homogeneous across the village and need not be suitable for all groups in the village. Hence, the impacts of these strategies are also extremely varied, having different repercussions.

Unsustainable use of community resources

Thirty to forty years ago, it was easier to find good quality wood in the *Banj* canopy of the Eiradeo forest. Today, one has to go further in to access even the shrubs in this canopy. Consequently, a large number of women are cutting/lopping trees (especially the ones in the *Chir* canopy) illegally, instead of picking up dry or dead fallen wood. Even the wood which is being purchased from the market and sold by neighbouring villagers is collected from the RF. This shows that all families use illicitly harvested fuelwood for almost five to six months in a year. The poorer families in the village may be doing so for the entire year. The present consumption of fuelwood, which is more than double the supply from the private and common land sources within the village itself, reflects this crisis. In the absence of any other sources of fuelwood and the lack of availability of commercial fuels, the villagers are left with no other option but to resort to illegal means of survival. Hence, all that are left in the forest today are some scattered *Banj* and *Buransh* trees, shrubs, and *Chir* trees, thereby resulting in immense ecological destruction.

The disappearing forest cover of *Banj* and *Buransh* trees, besides creating fuel and fodder crises, has affected the water sources of the region also Dhankalgaon itself had a dense undergrowth of *Banj* trees on the village community land many decades back, which, however, has completely disappeared today. Along with this, the disappearing *Banj* trees of the nearby Eiradeo forest has resulted in soil quality deterioration and in reduced availability of underground water in the region, and particularly in Dhankalgaon village. The fact that *Chir* trees are growing in abundance on village community land further amplifies the state of soil degradation. Underground springs (called *naulas*) are the only source of water,

used for all domestic purposes like drinking (both humans and animals), washing, and cleaning. There are only two ***naulas*** in the village, each belonging to one caste group. Presently, during the summer months, the quantum of water available from these ***naulas*** reduces substantially. The water crisis is worse for the ***Brahmin*** families as all 43 households are dependent on only one ***naula***. 'We can purchase fuelwood but we cannot buy water', said an elderly Brahmin lady, clearly indicating the need for enhancing water supply sources.

Failure of the VPF

The VP and other plantations developed on community land, primarily consist of *Chir* (*Pinus roxburghii*) trees Small numbers of the fuelwood species *Acacia* were also planted, which will, however, provide fuelwood only after a few years. Also, the thick canopy of the *Chir* trees allows very little light to permeate through and, therefore, deter the regeneration of other trees in their undergrowth. The plantation of fast-growing species like *Chir* helped in greening the once barren and degraded lands, but were unsuccessful in meeting the fuel requirements of the women, even after 37 years of protection The poor soil quality has also been responsible for the slow growth rate of the planted trees. While the objective of creating a VPF, as per the villagers, was to ameliorate the fuelwood scarcity faced by the villagers, the choice of species planted in the protected area and the management system devised do not reflect the aforesaid concern. The timber obtained from the *Chir* trees has multiple usage and the men are primarily interested in the commercial value of the trees rather than looking for daily subsistence needs.

Development of homesteads

Homesteads maintained by all individual households act as a supplementary source of fuel and fodder. The plantation of fruit, fodder, and fuel tree species in these small pieces of land is a means of meeting emergency needs of the villagers Surplus fruits sold in the market also provide cash income for the household

Continuous source of fodder supply

In spite of the failure of the VPF to meet a part of the fuel requirements of the village, the enclosed area has definitely been successful in supplementing the fodder supply for the villagers of Dhankalgaon The close proximity of these areas to the settlements has also relatively reduced the burden of the women in terms of fodder collection for the stall-fed livestock. *Pirul*, an important ingredient of the organic manure used in the agricultural fields, is also easily available from the VPF and other plantation areas.

Reduced agricultural productivity

Almost 34% of the dry collectible dung is being diverted from manure to fuel. Dung does not seem to be in short supply if its only use is to serve as cooking fuel. However, this shift towards fuel has a high opportunity cost in terms of the reduced availability of organic manure for agriculture. There are very few families in the village who can purchase chemical fertilizers from the market. The lack of adequate quantities of manure coupled with the absence of irrigation water, has brought down agricultural productivity to abysmally low levels. All families in the village need to purchase cereals from the market to substantiate their annual grains requirements.

Women's work burden

The severe forest depletion in the hills and the resultant natural resource scarcity has had maximum impact on the women in terms of increasing their daily work burden. This is particularly so in the case of the economically weaker households in the village who are entirely dependent on community resources for their energy consumption needs. Each trip to the forest takes a minimum of eight hours with most of the productive time being spent on fuel collection. On an average, it may be said that a woman walks 1800 km every year just for collection of fuelwood. Also, the time spent on water and fodder collection is increasing. In addition to the task of fulfilling the domestic chores, with the men moving out of the villages in search of employment, it is the women's responsibility to look after all agricultural operations. The reduced fertility of the agricultural land means that women have to put in more effort to achieve the same output.

Impact on health and nutrition

Due to the lack of availability of better species of wood, the natural adaptive strategy has been the shift towards *Chir* wood for fuel. However, *Chir* wood emanates smoke, which causes eye irritation. This is distinctly visible in older women, most of whom have red eyes which water constantly. The shrubs and dungcakes being used as cooking fuel also produce acrid smoke which affects the lungs, thereby increasing the incidence of cough. Women and small children exposed to this kind of indoor air pollution are the worst effected. Coupled with this, the increased time spent on harvest, collection, and use of biomass has negative effects on the health of women who perform most of these tasks. Carrying heavy headloads of wood over steep slopes and covering distances of 10 km or more in a day is a strenuous task. Also, with more time being spent on household chores, women have less time for rest and relaxation.

The acute water scarcity has put an end to the practice of vegetable cultivation in the agricultural fields along with the other crops. Vegetables cultivated at home were the only source of vitamins and nutrition for the villagers who otherwise consume a diet consisting of cereals and pulses only. Today, only a few families are able to grow vegetables in their homesteads due to the arduous nature of water transportation. Purchase of vegetables from the market to supplement their diet is rarely done and possible.

Improved quality of life with the use of biogas

The use of biogas as fuel has reduced the workload of the women in both households to a considerable degree, in terms of fuelwood collection and cooking time. Therefore, there is more time for agricultural activities and for relaxation.

Conclusions

The study reflects the changes that have taken place in the livelihood systems of the people of Dhankalgaon over a period of time as a result of the severe natural resource crunch being faced by them. While most of the survival strategies have been adopted at the individual level, a few have been at the community level also. However, most of the coping strategies that are visible today at the village level are unsustainable from the environmen-

tal and ecological point of view. This is clearly visible from the resultant impacts of these strategies like excessive exploitation of the community reserve forest at Eiradeo, the adverse effect on the health due to the usage of inferior fuels like dungcakes, shrub-wood and *Chir* wood for cooking, and the long working hours of the women to ensure the stability, survival, and growth of their families. Under these circumstances, a concerted effort is required to bring back the concept of a sustainable village ecosystem which will be in harmony with nature. Development of the resource base inclusive of the water and biomass is the most essential requirement at present. However, these alone might not be sufficient to fulfill the requirements of the people on a sustainable basis, and, hence, need to be supplemented by external inputs like commercial fuels and renewable energy sources. In addition to enhancing the resource base of the village, development of institutions and capacity building at the village level is also required so as to enable them to design their developmental requirements themselves.

The unabated use of biofuels for domestic energy needs and its impact have been clearly elicited in the earlier sections of the case study. Since 132 other villages have settlement rights over the government reserve forest at Eiradeo, the stress on this resource patch for meeting the daily biomass requirements is much higher than its regenerative capacity. Alternatively, it becomes necessary to enhance the capability of the village itself to meet its biomass fuel and fodder requirements. The creation of the VPF by the people of Dhankalgaon in 1958 was meant to ameliorate the fuelwood crisis at that time and also to cater to future requirements. While the village VP has been successful in ensuring a steady supply of fodder for the village livestock, not much has happened in the field of fuelwood distribution. *Chir* is the main species of trees planted in these areas; however, because of the poor soil quality of the land the growth rate has been extremely poor. However, a scientific system of lopping every few years will help to meet fuelwood needs of the villagers partially, however small a fraction it may be.

To begin with, the villagers would require some external support both in the form of technical back-up through the Forest Department and managerial support through a non-governmental organization. Some technical expertise will help to ensure sustainable usage and development of the VPF. The village requires more afforestation programmes for the plantation of fast-growing fuelwood species. Soil and moisture conservation techniques need to be applied along with the afforestation programmes on community land and, if possible, even on private land to restore the soil fertility

At present, the VP committee comprises only male members and even among them the *Sarpanch* is solely responsible for its success or failure. Besides the fact that fuelwood is not the priority of the committee members, a greater involvement of all villagers, especially the women, is necessary for the survival of this community effort and its efficient utilization and management Community training, for both capacity building and institution development, will help the group in identifying themselves with the asset created, and, therefore, rejuvenate the VPS. This involvement can be brought about with the help of local grassroots organizations.

While, on one hand, biomass fuels gathered from community resources continue to be the primary source of domestic fuel for the poor sections of the village, particularly the *Shilpakar* community, on the other hand, another section of the village community has

resorted to the use of commercial fuels to save the time and effort required for biomass fuel collection and processing. Hence, in addition to improving the VPF of the village, it is equally important to look at the supply situation of commercial fuels. The supply of kerosene and LPG in and around Dhankalgaon village is very irregular and inadequate. Kerosene supply through the public distribution system is rather inadequate and has to be purchased from private shops in the Bhogwalipokhar market, at a much higher price. Similarly, LPG cylinders, when available, have to be purchased from Ranikhet, 25 km away from Dhankalgaon. Hence, availability of commercial fuels may be a constraint in its adoption, even by the households who can afford it. Under these circumstances, a more efficient supply infrastructure of commercial fuels will at least meet the demands of a section of the population who can afford the same. This, in turn, will help to reduce, to a certain extent at least, the pressure on biomass fuels, and, at the same time, enhance the quality of life of the people.

The severe stress on biomass fuels, coupled with the scarce availability of commercial fuels in the hills, provides a case for the promotion of alternative renewable energy technologies. Biogas has proved to be a viable renewable energy technology for those households who have the requisite number of cattle, space, and water in the village. In order to further expand the programme in the village, under the present conditions of resource scarcity, water and cattle resources need to be developed with the help of external inputs. The acute water scarcity situation, both for drinking and for irrigation, has developed over the last decade. What is, therefore, required is the construction of rain water harvesting structures or of handpumps, wherever possible. The low lying areas of Dhankalgaon (the valley areas) have relatively high underground water tables, and, hence, could be the ideal ground for the construction of handpumps. However, the huge expenses involved are beyond the villagers' scope for investment, and, hence, governmental and or non-governmental support needs to be extended to most of the villages situated in the Gagas river watershed.

While the quantity of fodder available in the village has increased with the promotion of the VPF, it is equally necessary to improve the quality of fodder. For this, better strains of fodder grass may be sown in the VPF once a better management system is devised. Fodder grass does not require the water and care required for cultivating fodder crops, but provides a good amount of nutrition. Good quality feed provided to the livestock will help to improve the livestock health and increase the average collectible dung. Increased dung availability would also require an increase in the number of cattle owned by each household A policy whereby cattle loans could be linked up with biogas plant loans, would make the purchase of cattle easier for the beneficiary. As per the established standards of installation of 2 m^3 biogas plants, a minimum of 50 kg of cowdung every day is required, which means that one should have at least four cattle heads. Apart from the two families who already have biogas plants installed in their houses, at present there are six other families in the village who have four or more cattle heads. In Dhankalgaon, livestock maintained is mainly of the non-milch type which provides small amounts of dung. There are 19 families having at least three cattle heads Hence, an integrated programme of livestock development, which includes cattle loans and fodder development schemes, should be targeted at this group

A sustainable biogas programme would also require an efficient monitoring and maintenance system, which will make spare parts available and repair the defects as soon as possible. The existing biogas plants were installed by a local grassroots organization and, under the present system, the villagers themselves go to the organization office at Ranikhet, to register a complaint. This is not only expensive, but also time consuming and may be fruitless if the concerned person is not available.

A number of coping strategies adopted by the people were observed during this study of Dhankalgaon. This included a diversification of activities, increased dependence on wage labour and employment outside, dependence on the market for household inputs by the economically better-off families, and increasing reliance on common property by the poor households. In conclusion, one can say that the case study of Dhankalgaon aptly reflects the need to formulate policies which affect the livelihood systems of people, after taking into consideration the knowledge and skills of the local people. As is happening in most other rural areas of the country, the women from Dhankalgaon also work longer hours than the men. This is closely interlinked with biomass resource degradation like the shrinking forest cover, the reduced fertility of agricultural land, the water scarcity, and the increasing number of forest fires occurring in the Kumaon hills of Central Himalaya While common property resources continue to be the mainstay of the poor for fulfilling their livelihood requirements of food, fuel, and fodder, it is necessary to enhance the regenerative capacity of these resources while recognizing the intricate inter-relationship between forest–crop–livestock–energy systems No single sub-system can be considered in isolation A policy related to one of these sub-systems is bound to affect the other livelihood sub-systems

References

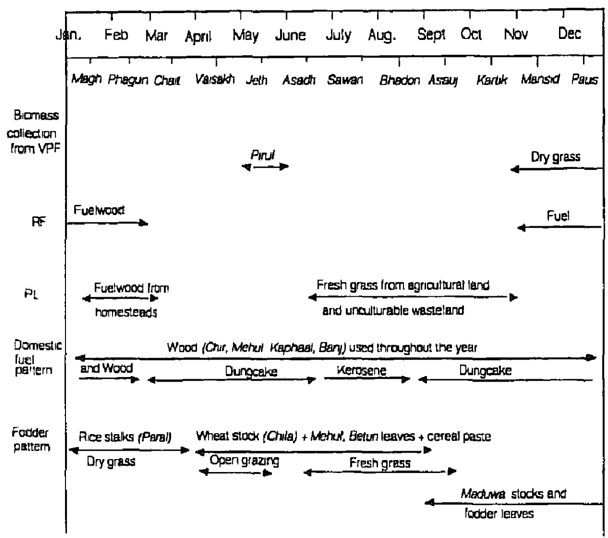
Agarwal B 1986 *Cold Hearths and Barren Slopes*. New Delhi Allied Publishers.

Kirk S 1993 Household fuels and health *Urja Bharati* 3(3): 31–32 New Delhi: Ministry of Non-conventional Energy Sources

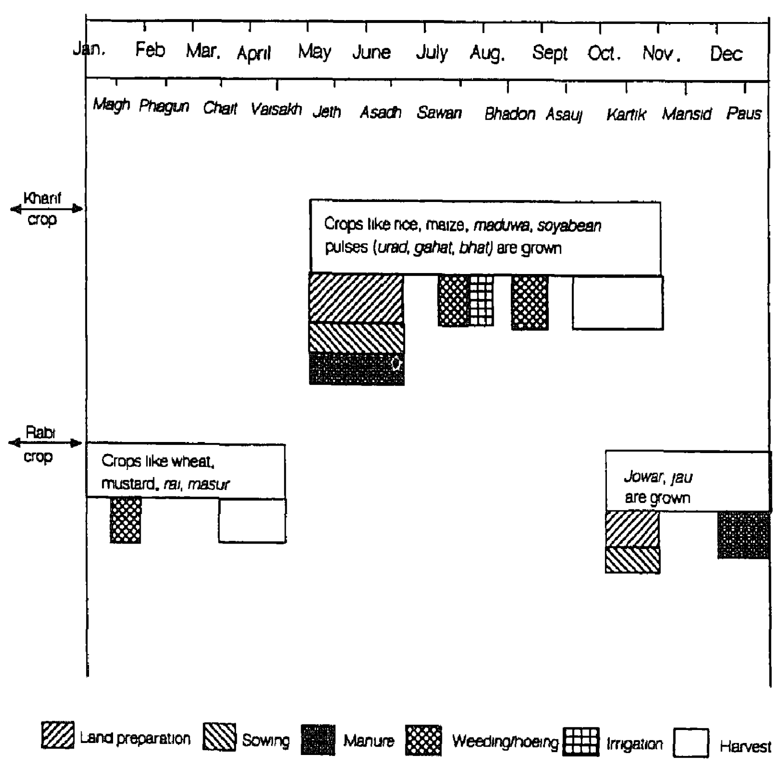
Laurie H 1995 Livelihood security in mountain ecosystems coping and adapting in two Himalayan villages University of Manitoba Winnipeg Technical report no. 5

Mukherjee A K 1994 India's forests A status report – concepts, definitions, trends, controversies. New Delhi: Ministry of Environment and Forests, Government of India

ANNEXURE 1
Seasonality in biomass resource use and collection



VPF van panchayat forest RF Eiradeo Reserve Forest PL private land



BIOMASS WOOD RESOURCES IN THE CENTRAL HIMALAYAN REGION: AN ANALYSIS OF SUPPLY AND CONSUMPTION

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Introduction

Increasing biotic pressure has led to a severe fuel and fodder crisis, which, in turn, has led to an enormous disturbance in the highly fragile Himalayan ecology. This has generated a global debate on preparing and implementing special strategies for natural resource conservation and sustainable development in the area With an acute shortage of natural resources on one hand and large demands on the other hand, the developing countries are faced with situations which not only appear to be unsustainable but also unavoidable due to their close link with human subsistence Biomass systems in the hills, particularly in the Himalayas, are examples of such situations.

In this paper, a methodological framework for understanding the stress on village-level wood resources due to domestic energy use is presented. The analysis of stress and an understanding of the dependence of people on local biomass is used to propose a sustainable biomass management plan. The methodology is applied to four villages in the hills of Western Uttar Pradesh, namely, Agrora, Ghiri, Bhainsro, and Bhimalli-malli in the Irgad micro-watershed of the Garhwal district.

Methodology

All the land within the village boundary, termed as total village land, was classified into three strata, namely, homestead, agricultural land, and forest land. This classification is

based on the present land-use pattern, however, forest land includes *panchayat* forests, community land, barren land, temple and school plantations, etc., which lie within the village boundary. All the relevant land records were taken from local *patwaries*[1]. The methodology was based on complete enumeration, so all the trees with at least 20 cm girth at breast height (GBH) were enumerated by a measuring tape. Very big trees which are never lopped or cut for fuel or fodder because of religious or sentimental importance were excluded from measurements. The height of five trees of each species randomly selected in every village was measured using *Abney's Hand Level*. The following general form equations were used to formulate regression equations for height and volume (Arp, McGarth, Beck 1987; Chaturvedi 1984; Mohns, Applegate, Gilmour 1989).

1. $H = a + b \times G$;
2. $V = a + b \times G^2 \times H$; and
3. $V = a + b \times D^2 \times H$.

where V is volume (in cubic metres), H is height (in metres), G is GBH (in metres), D is diameter at breast height (DBH) (in metres), and a and b are regression constants.

From the information gathered on GBH for all the trees in different species, the total basal area was computed. Basal area is a product of the mean basal area in girth class and the number of trees. The sum of the basal area in different girth classes revealed the basal area occupied by different species, which, in turn, computed the total basal area. All the species which contributed less than three per cent of the total basal area, individually, were clubbed as miscellaneous species. Fruit trees were also included. The remaining two to six species in all the villages were considered as major species and volume for these species was calculated separately using regression equations. Wood volume computed in terms of cubic metres was converted to tonnes by following the standard conversion (1.5 m^3 = 1 tonne).

The volume generated by various species under different strata was aggregated to compute the total growing stock in the village, over which annual sustainable yield was calculated using Van Montal's Formula (Davis 1966):

$$Y = 2 \times \frac{GS}{R}$$

where Y is sustainable yield (tonnes/year), GS is growing stock (tonnes), and R is the rotation of growing stock in village (average 50 years). Keeping in view the various damages due to biotic interferences, natural calamities, and unpredicted losses, half of the annual yield was regarded as the sustainable yield.

A household-level survey was conducted to estimate the amount of fuelwood used for various end uses, i.e., cooking, space heating, and water heating in different seasons (Zutshi *et al* 1991). The annual fuelwood consumption in a village was compared with the annual

[1] Village level revenue officers

sustainable yield and the stress factor was computed by using the following formula:

$$\text{Stress} = \frac{\text{Annual total consumption}}{\text{Annual sustainable supply}}$$

Results and discussion

The major species found in the district are *Banj, Chir, Kail, Deodar*, etc. In the selected villages of the study area, only four species occupy more than three per cent of the total basal area. The prominent species like *Chir, Deodar*, and *Banj* have been completely removed from the village forest lands for fuel, fodder, timber, and agriculture. Generally, *Kharik* and *Bheemal* have dominated agricultural land and homesteads, whereas *Banj* and *Chir* have contributed the highest (60–80%) to the total woody biomass. But, at higher altitudes, *Banj* contributed 20–80% of the total biomass. The sustainable yield was much higher on village forest land than on agricultural land and homesteads. This was due to the dominance of pine trees in the forests. The maximum total growing stock (1158 tonnes) was observed in Bhimalli-malli village, whereas the minimum (916.5 tonnes) was recorded in Bhainsro village and reflected an annual sustainable yield of 46.32 and 36.66 tonnes, respectively. Generally, woody biomass was contributed by prominent timber species in all the strata, in every village. However, fodder species also gathered a good amount of biomass. This reflects on the fact that for various energy and non-energy uses, fodder species as well as second-graded timber species have been excessively harvested. The low productivity under homesteads can be attributed to the unavailability of land, as well as very little basal area generated under trees in this stratum.

In the process of rapid harvest, people have been consuming the growing stock beyond the annual increment. The species-mix, with *Bauhinia* spp, *Grewia optiva, Celtis australis, Quercus leucotricophora, Pinus roxburghii*, etc., as the predominant species, suggests that the preferred fuel species have already been removed, and, now, people are either consuming less preferred species or harvesting the preferred species from the government forest resources In both the cases, the natural regeneration of preferred species is suppressed.

Bhimalli-malli supports 50 families on 33.2 ha of land. The total woody biomass was found to be 1778.47 tonnes, which generated an annual sustainable yield of 46.32 tonnes (Table 1). *Chir* provided 69% of the total yield, and forest land contributed about 90% of the total woody biomass (Figure 1).

Agrora supports a growing stock of 1059.32 tonnes on 105.2 ha of land for 48 families to share. Village forest land had a fairly good stock to contribute 82.6%, followed by 13% on agriculture land and 4.4% on homesteads (Table 2), which generated an annual sustainable yield of 36.19 tonnes (Figure 2).

Bhainsro supports 27 families on 51.2 ha of land with 916.5 tonnes of woody biomass. A major portion was derived from *Chir* (79%). However, *Banj* and miscellaneous species share 19.2 and 2.1%, respectively (Figure 3). The maximum woody biomass (98%) was derived from village forest land whereas homestead and agriculture land contributed 1.2

TABLE 1
Biomass distribution in various strata under different tree species in Bhimalli-malli

Stratum	Growing stock (tonnes)	Percentage	Total sustainable yield (tonnes/year)	Area (ha)	Yield/ha (tonnes/ ha/year)
Agriculture land	84.59	7.30	3.38	18.36	0.18
Homestead	33.44	2.88	1.34	—	—
Forest land	1040.04	89.81	41.60	10.36	4.02
Total	1158.07	100.00	46.32	—	—

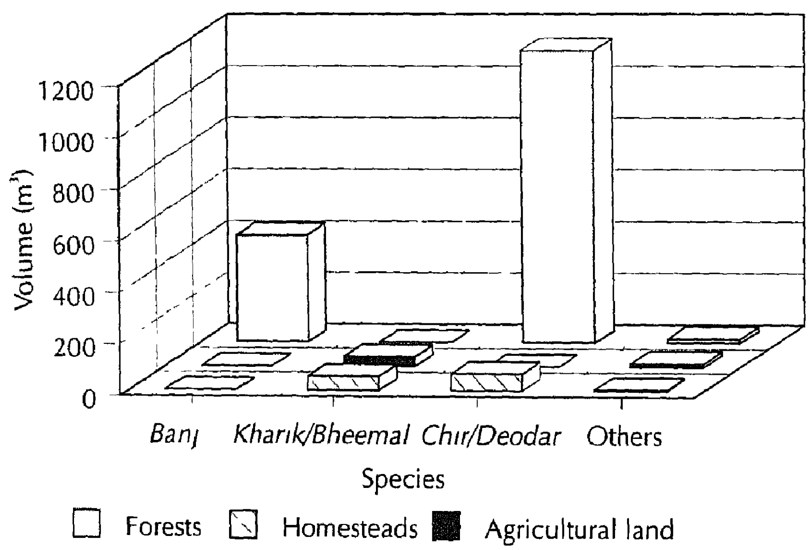


Figure 1. Status of tree biomass in Bhimalli-malli

and 0.9% of total woody biomass, respectively. The sustainable yield obtained from village forest land, homesteads, and agricultural land was 35.88, 5.70, and 1.92 tonnes, respectively (Table 3).

TABLE 2
Biomass distribution in various strata under different tree species in Agrora

Stratum	Growing stock (tonnes)	Percentage	Total sustainable yield (tonnes/year)	Area (ha)	Yield/ha (tonnes/ ha/year)
Agriculture land	142.46	13.00	5.70	43.28	0.13
Homestead	47.92	4.38	1.92	—	—
Forest land	904.94	82.62	36.20	15.12	2.39
Total	1095.32	100.00	43.81	—	—

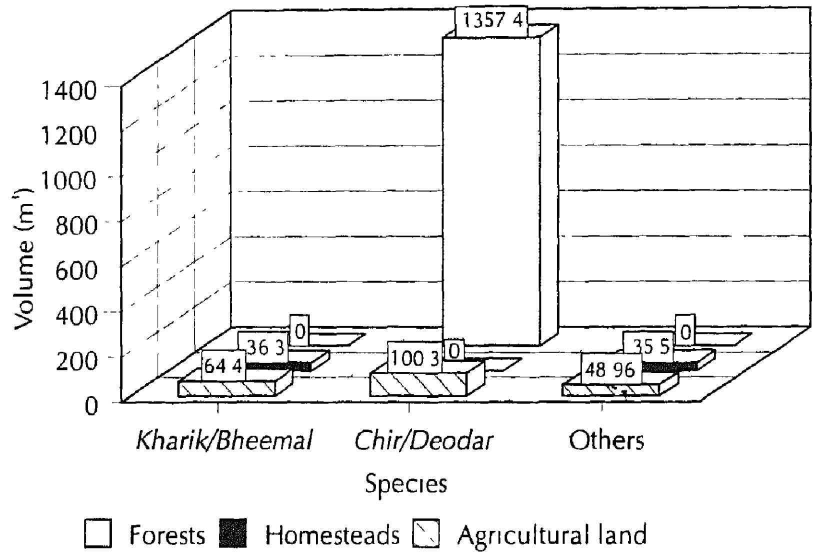


Figure 2. Status of tree biomass in Agrora

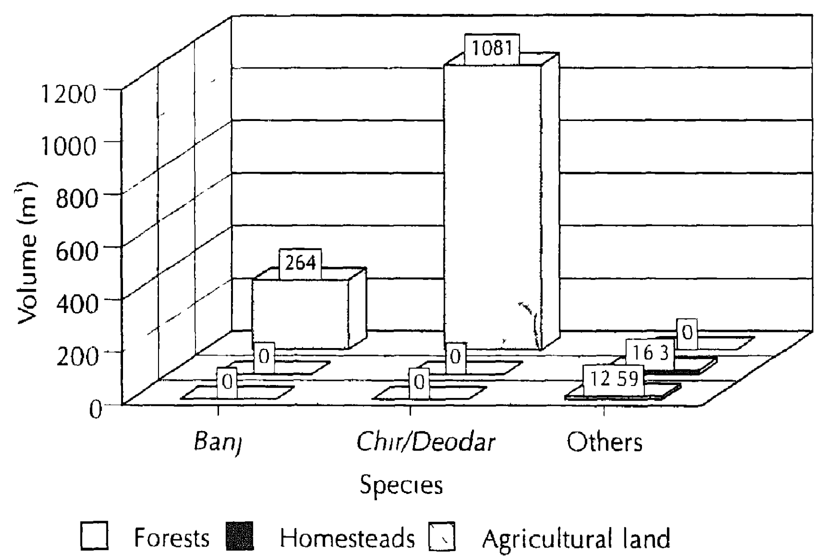


Figure 3. Status of tree biomass in Bhainsro

TABLE 3

Biomass distribution in various strata under different plant species at Bhainsro

Strata	Growing stock (tonnes)	Percentage	Total sustainable yield (tonnes/year)	Area (ha)	Yield/ha (tonnes/ ha/year)
Agriculture land	8.40	0.90	0.336	28.16	0.012
Homestead	10.90	1.20	0 436	—	—
Forest land	897.20	97.90	35.880	12.66	2.830
Total	916.50	100.00	36.660	—	—

Ghiri supports 60 families on 61.7 ha. The total stock of woody biomass was 127.7 tonnes to which miscellaneous species contributed 17%. However, ***kharik*** contributed 80.6%. The share of woody biomass from village forest land is nil, probably because the stratum was devoid of woody vegetation (Table 4). Homesteads contributed only 4% to the woody biomass, whereas agriculture land contributed 96%, and generated an annual sustainable yield of 4.86 tonnes (Figure 4).

Stress

The stress factor is the ratio by which total annual consumption exceeds annual sustainable yield The data tabulated in Table 5 revealed very high stress levels on woody resources in different villages of this study. The total consumption of fuelwood varied between 1.48 and 2.36 times the woody biomass supply in Bhainsro and Ghiri village, respectively.

TABLE 4
Biomass distribution in various stratum under different plant species at Ghiri

Stratum	Growing stock (tonnes)	Percentage	Total sustainable yield (tonnes/year)	Area (ha)	Yield/ha (tonnes/ha/year)
Agriculture land	117.10	96.20	4.68	25.80	0.181
Homestead	4.60	3.80	0.18	—	—
Forest land	—	—	—	2.46	—
Total	121.70	100.00	4.86	—	—

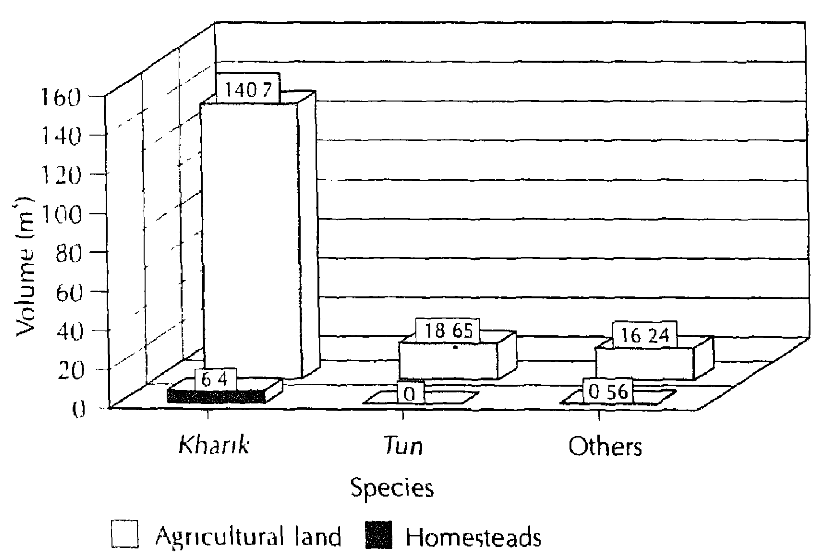


Figure 4. Status of tree biomass in Ghiri

TABLE 5
Stress on biomass resources in different villages

Village	Annual sustainable yield (tonnes)	Annual total consumption (tonnes)	Stress
Agrora	43.81	89.40	2.04
Ghiri	4.86	11.48	2.36
Bhainsro	36.68	54.40	1.48
Bhimalli-malli	46.32	90.30	1.95

Enormously high stress essentially reflects that the stock standing within the village boundary, i.e., the revenue land, is not able to meet the local demands, and people have to use wood resources from forest land.

Stress computed for all the villages reflected a rapid rate of removal of growing stock itself, besides the sustainable yield. This trend of felling may explain the low productivity of common lands in general and removal of preferred fuel and fodder species in particular. The data reveal that the supply from wood resources was not sufficient to meet the local energy demand. In some of the villages, stress had attained very high values which can probably be explained by the shortcomings of the conventional tree biomass planning methodology listed below.

1. Biomass had been enumerated within the village boundary only, whereas people may have had access to government land and neighbouring villages also. So sustainable yield was on the lower side.
2. The adopted methodology excluded shrubs and enumerated only the growing stock which had a GBH above 20 cm.

Generally, stress was higher in the village where community land, i.e , village forest land, had been excessively harvested. The situation was almost irreversible in the villages where prominent timber, fuel and fodder species had already been removed or reduced to occupy less than three per cent of basal area. Higher productivity on agricultural land, where trees were generally scattered along bunds and contours, as compared to village forest land essentially reflected poor woody crop. However, on the other hand its lower productivity might not reflect over-exploitation of agricultural land. On the contrary, it might reveal the presence of a fairly good wood stock in the vicinity, which, in case of over-exploitation, should be devoid of preferred timber, fuel, and fodder species, as was prominent in the villages under study.

Future biomass development programme

Environmental degradation caused by stress on biomass resources, in the form of denudation, land degradation, and depletion of natural resources, emphasizes the need for better

management of resources – land, water, and green cover – through detailed management plans having a multi-disciplinary approach (George 1989; Chetty, Reddy, 1991).

Having obtained the information on present biomass supply for energy and non-energy uses as well as energy consumption pattern, it is necessary to ensure a rational utilization of biomass resources for various end uses (Soussan 1991). This can be brought about by using the resource more efficiently, e.g., improved cookstoves and biogas for cooking. Also, depending on the extent of biomass shortage, it is necessary to augment the energy supply through implementing various energy programmes and technologies after studying the feasibility of the same. The following list presents a number of technologies and programmes that can be adopted:

- solar heating equipment;
- solar photovoltaic systems;
- biogas plants;
- smokeless *chulhas*;
- small hydro systems;
- wind power generators;
- fuelwood plantations;
- biomass gasifiers;
- hydrams; and
- efficient use of biomass.

References

Arp P A, McGarth T P, Beck J A. 1987. A parameter based method for modelling biomass accumulations in forest stands. theory. *Ecological Modelling* 36(1–2): 29–48.

Chaturvedi A N. 1984. Assessment of biomass production. *Indian Forester* 110(8): 726–738.

Chetty C V R, Reddy M N. 1991. Information system for assessment of biomass production and management in dry land ecosystem. Paper presented at the *National Workshop on Information Systems for Watersheds in Dry Land Ecosystem*. 4–7 June 1991, Mysore.

Davis K P. 1966 *Forest Management. Regulation and Valuation.* Edition II. London. McGraw Hill Book Company. pp. 110–115.

George R. 1989. Observations related to household level research on energy (fuel) resource consumption. pp. 90–102. *Paper presented at the Workshop on Decentralized Rural Energy Planning and Implementation* Baroda: Operations Research Group.

Mohns B, Applegate G B, Gilmour D A 1989. Biomass and productivity estimation for community forest management: a case study from the hills of Nepal. II. Dry matter production in mixed young stands of Chir pine (*Pinus roxburghii*) and Broad-leaved Species. *Biomass* 17(3) 180–184

Soussan J 1991 Building sustainability in fuelwood planning *Bioresource Technology* 35· 49–56.

Zutshi P, Bose R K, Prasad R, Joshi V 1991. Energy consumption pattern in Garhwal hills Discussion paper. New Delhi: Tata Energy Research Institute.

INTERVENTION OF BIOMASS ENERGY SYSTEMS – A CASE STUDY OF A PERI-URBAN VILLAGE: DHANAWAS

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Introduction

Village Dhanawas is situated in the south-west part of the Gurgaon district in Haryana, with the nearest town, Farrukhnagar, 7 km away. It consists of 189 households with a total population of 1056. The majority of this population belongs to the *Ahir* community, and *harijans* constitute 10% of the total population. The total geographical area of the village is 569.1 acres, out of which 105 acres belong to the village *panchayat*. The cattle population in the village is 450, including 210 buffaloes, 44 cows, and 196 calves. Its infrastructural facilities include a junior secondary school, a temple, and a community centre. The village is also electrified. The main occupation of the people is agriculture and cattle-rearing. The main crops of the *rabi* season are wheat, barley, mustard, and gram, and the *kharif* season crops include *jawar*, *guwar*, *bajra*, and groundnut.

Energy interventions

Various energy intervention activities have been initiated by TERI in the village, with the main objective of developing and demonstrating of renewable energy technologies. The demonstration was aimed to provide a feedback on the performance of the devices and to understand the possible hurdles and bottlenecks for further implementation as well.

The energy plantation was the first activity to be taken up in 1984. This was taken up in 20 acres of extremely degraded and waterlogged land which belonged to the *panchayat*.

This waterlogged land had a pH value of more than 9. As an effort to improve its quality, the land was treated with dilute sulphuric acid to check the spread of salt. Drought-resistant species like *Acacia nilotica* and *Prosopis juliflora* and species which can withstand waterlogging like *Terminula arjuna*, and *Syzysgium cuminii*, etc., were planted (TERI 1994). Over the years, several other energy technologies were introduced, the details of which are given in Table 1.

There have been several changes due to the various available energy interventions, specially those related to biomass. The *chulhas* and the biogas plants serve to conserve substantial quantities of biomass. There is also an augmentation of fuel supply due to the plantation. It may be mentioned here that efforts have been made to involve the villagers in all the endeavours. The institutional set-up is given in Figure 1.

An attempt has been made to quantify the fuel savings due to various biomass energy interventions. The data used for calculations is based on experiments conducted by TERI in the village.

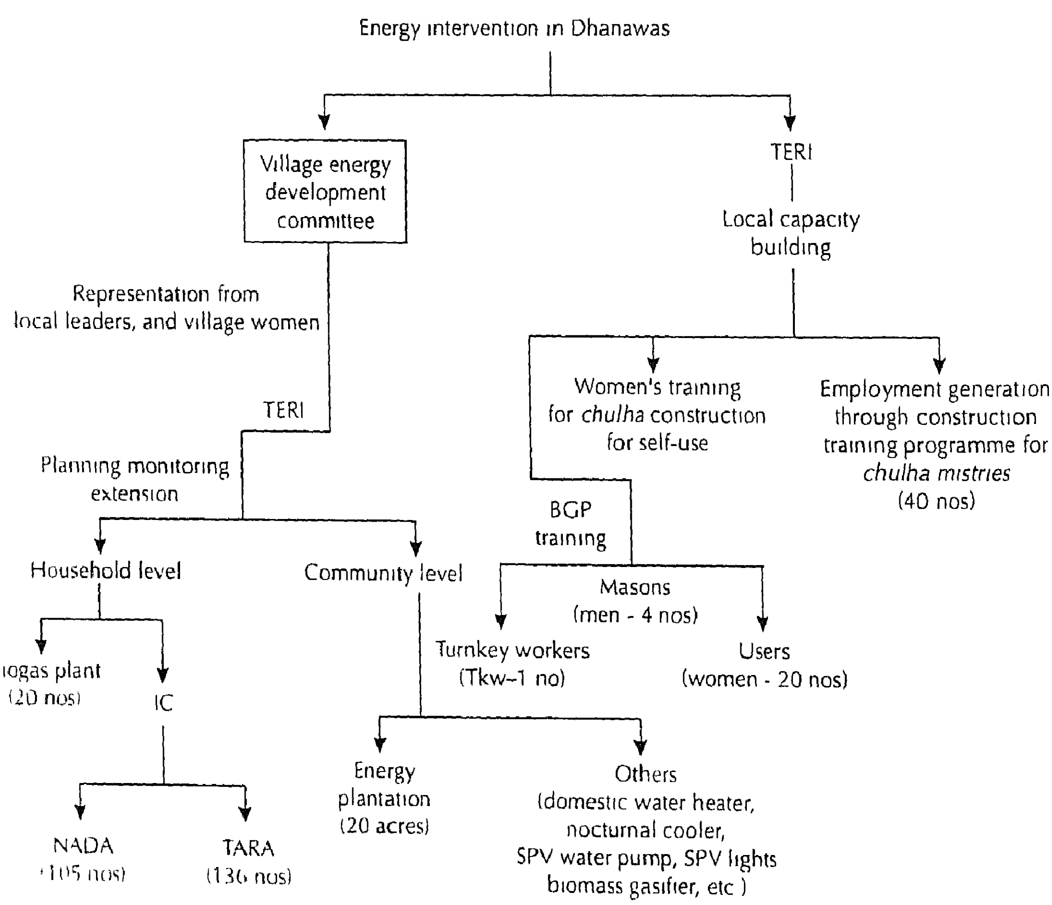


Figure 1. Energy intervention in Dhanwas

TABLE 1

Energy technologies introduced in Dhanawas

Technologies/ year	Objective	Performance	Demonstration efforts and further extension	Response by villagers	Problems/constraints
Energy plantation (20 acres)/1984	Increase the firewood availability in the village; reclamation of degraded land	Growing stock ~339.59 quintals; annual production of grass ~300 quintals	Villagers have planted trees on the bunds of their farmlands also	Benefits: fodder grass to villagers free of cost; income from wood sale accrues to village energy development committee (VEDC); generates employment for villagers by providing wage labour	The only benefit to individuals is fodder availability
NADA cookstoves (*chulhas*) (105 nos)/ 1986–92	To promote an efficient and improved *chulha*; to reduce the smoke problem in kitchen	The evaluation carried out in June 1990 indicated that 55% were in use; women appreciated their 'smokelessness'	40 women were trained in the construction of *chulhas*	Trained women constructed *chulhas* in their own houses, and in other houses as well	Some *chulhas* got destroyed by rains; renovation of houses caused the abandoning of many *chulhas*
TARA *chulhas* (136 nos)/ 1987/88	To promote an efficient and improved *chulha*	An evaluation after 18 months of dissemination indicated that 65% households have purchased these because of portability and 35% due to the fuel and time saving	—	Led to a replacement of mud portable *chulhas*	*Rotis* could not be conveniently baked on it; ashes fell on the floor which led to its blackening, the metallic bodies would get extremely hot and increased the chances of burn injuries; due to the small size of firebox, wood would have to be cut in small pieces

Contd...

Table 1
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Technologies/ year	Objective	Performance	Demonstration efforts and further extension	Response by villagers	Problems/constraints
Biogas plants (20 nos)/ 1985–95	To develop a model, which would be ▪ cost-effective ▪ easy to maintain; and optimizes hydraulic retention time (HRT)	19 plants are functioning and are being used satisfactorily	Demand for biogas plants in nearby villages has increased	Non-polluting fuel; biogas slurry has improved productivity of farmlands and is useful for mushroom cultivation; provides an option of lighting; employment generation for trained biogas masons.	Less gas production in winter season; lack of own finances and the problem in procuring bank loans are demotivating factors
Biomass gasifier (1990)	To produce briquettes and explore the possibility of mass production and commercialization; to provide electricity supply for the temple and streetlights in the village	6 kWh capacity was installed under a demonstration project	Performed well with the replacement of 70% diesel in the diesel engine	The system was found inefficient to provide electricity for streetlights as well as for making briquettes; it has to be upgraded	Inadequate due to low capacity
›olar cookers (6 nos) 1985	To examine their viability in the rural set-up	Used for a very short time	Overall acceptability: poor	People were willing to try, but it has limitations in cooking some items	The size is inadequate to cook food for large families

Note. NADA *chulha* – improved *chulha* (IC) fixed mud model; TARA *chulha* – portable metallic model.

Estimation of energy saving

In this section, an attempt has been made to quantify and impute a monetary value for the energy saving brought about by the interventions. The interventions which have been taken into account are:

- TARA *chulhas*;
- NADA *chulhas*;
- biogas plants; and
- energy plantations.

The following assumptions have been made for calculations.

- Average energy consumed per adult by the use of traditional cookstoves (TCs) is 22.14 MJ/day, while, for a combination of TARA and TCs it is 19.55 MJ/day, and for NADA *chulhas* 19.32 MJ/day. This is based on the experiments carried out earlier (Pal, Joshi 1989)
- For biogas, a stove efficiency of 40.5% has been assumed (Kishore, Raman, Ranga Rao 1988).
- Calorific value for the biogas (CH_4) has been taken as 21.45 MJ/m^3 (Kishore, Raman, Ranga Rao 1987).
- The efficiency for the TC as 12% and the calorific value of wood as 3585 kcal/kg has been taken for the computation of fuelwood replacement by the use of biogas plants (Ravindranath, Hall 1995).
- For ICs and biogas plants, the total energy saved has been calculated on the basis of the actual duration of use of the device. Out of the 136 TARA *chulhas* installed in 1987/88,75 were in use for 360 days and 61 for 720 days. And, out of the installed 105 ICs (NADA *chulhas*) during 1986–92, 47 were in use for one year and 58 for two years.
- Fuelwood from the plantation has been quantified on the basis of the enumeration of trees. 60% of the growing stock has been taken as an estimation for air-dried fuelwood.
- For the fuelwood saving brought about by ICs and biogas plants, a market price of Rs 0.80/kg of air-dried wood has been considered.
- An average life of two years has been considered for mud ICs.

The fuelwood saving from biomass energy systems from 1985 to 1995 are shown in Table 2.

The wood saving due to the use of biogas interventions has been estimated based on the conversion of biogas to wood equivalent. Biogas consumption was measured in selected households and also the operating days per year monitored. The gas consumption per plant/s was calculated over the year. Similarly, the fuel saving due to the use of ICs over that of TCs was calculated. Further, sustainable yield from the energy plantation has been taken as the wood available to meet the energy needs.

TABLE 2
Fuelwood saving from biomass energy systems (1985–1995)

Type of device	Number of devices	Replacement of fuelwood (tonnes)	Monetary value (Rs)
TARA	136	67.35	53882.58
NADA	105	60.68	48541.26
Biogas plant	20	164.08	131264.00
Energy plantation (acres)	20	203.75	163003.20
Total	—	495.86	396690.04

In addition to these quantitative savings, several qualitative benefits have also accrued to the people. This has contributed to an overall improvement in the standard of living. People in the neighbouring villages have been influenced by the programmes carried out by TERI. As a result, the acceptance of various technologies has improved in the region. Table 3 captures various qualitative and quantitative benefits as gathered from various surveys and discussions with the villagers.

Conclusions

The interventions of biomass energy systems have brought in several qualitative and quantitative changes in the village. The notable qualitative changes that need mention include

TABLE 3
Qualitative and quantitative benefits of the various technologies

Activity	Qualitative	Quantitative
Energy plantation	Reclamation of waste land and production of woody biomass	Growing stock ~ 339.59 quintals
Improved *chulhas*	Smokeless, fuel and time saving, kitchen cleanliness, etc.	12.74% fuel saving[a]
Biogas plants	Time saving, convenient and non-polluting fuel, alternative use of dung, etc. (prioritized by the users)	19 biogas plants functioning well; biogas slurry has increased in the yield of various crops from 6.5 to 16%; replacement of fuelwood: 14.92 tonnes per year
Biomass gasifier	Alternative for low-cost energy and efficient fuel in the form of briquettes	70% diesel saving in diesel engines[b]

[a]Pal, Joshi (1989); [b]TERI (1994).

a change in the quality of life of women due to saving of time, smokelessness, etc. Men also appreciate the benefits of using biogas slurry in the fields as fertilizer, which, otherwise, was burnt in the *chulhas*. The interventions have been able to save or avoid burning of about 495.86 tonnes valued at Rs 396 690 of fuelwood since 1985.

References

Kishore V V N, Raman P, Ranga Rao V V. 1987 *Fixed Dome Biogas Plants – A Design, Construction and Operation Manual* New Delhi Tata Energy Research Institute.

Kishore V V N, Raman P, Ranga Rao V V. 1988. The biogas systems for cooking energy production – is it more efficient ? *Biogas Forum* **32**: 2–9

Pal R C, Joshi V. 1989. Improved woodstoves for household energy managements – a case study. *Productivity* **30(1)**: 53–59.

Pal R C. 1994 Promotion of biogas technology – some lessons from the field *Changing Villages* **13**(4). Oct.–Dec. 1994

Ravindranath N H, Hall D O 1995 *Biomass, Energy and Environment* New Delhi Oxford and IBH.

Sangeeta K, Ranga Rao V V, Pal R C, Sadaphal P M, Joshi V 1988 Impact of energy development activities and user's needs – a case study TERI Discussion Paper No. 36. New Delhi. Tata Energy Research Institute.

TERI 1994. *Sustainable energy development in Dhanawas – a case study.* New Delhi Tata Energy Research Institute

Section 2

Biomass processing and liquid fuels

BIOMASS FEED PROCESSING FOR ENERGY CONVERSION

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Introduction

Biomass is a natural product of solar energy, and, therefore, a renewable source of carbon and hydrogen, which are the basic constituents of energy and chemical products. Worldwide, the energy stored in biomass through photosynthesis is approximately 3×10^{21} J (90% in trees) every year, which is nearly 10 times the world's annual energy use (Hall, Overend 1987). Even though the total renewable biomass resource for energy far exceeds the world's total energy requirement, its volume exploitation remains limited because of the present low cost of fossil fuels, the heterogeneous nature of biomass, and the area over which the biomass must be collected for large-scale applications

Biomass should be termed not only as a potential renewable source of energy, but also as a renewable feedstock for chemicals. Technologically, biomass can provide all the forms of energy and the products normally derived from fossil fuels. However, presently, these cannot compete with fossil fuels in scale and capacity Meanwhile, biomass can be an attractive source of solid fuel, either for its direct use or through conversion routes to meet growing energy demands and to replace and conserve fossil fuels. For most of the developing countries, devoid of oil resources, biomass is a necessity. Furthermore, there are worldwide wood shortages, and people in rural areas are resorting more and more to agro-residues and cowdung. Also, these resources are highly under-utilized in developing countries due to inefficient combustion and cause widespread environmental pollution with associated health hazards.

Compared to coal and oil, the carbon and hydrogen constituents in biomass are highly oxygenated, which are responsible for their lower heating values. Their varying moisture and ash contents and comparatively lower bulk densities are additional constraints to their utilization for energy. Bulk densities of some typical materials are given in Table 1.

Biomass feed, especially agro-residues, is available in different forms, such as husks, straw, and stalks of various and numerous crops. Due to this heterogeneous nature, the utility of these materials for energy becomes limited, and energy conversion processes tend to become biomass specific. In order to enhance the effective utilization of these materials, it becomes imperative to 'prepare' these materials. These processes comprise drying, commutation, compaction or briquetting, and carbonization to produce clean fuels. These feed preparation techniques add to convenience, both for the collection, transportation, and storage of these materials, and their efficient utilization for energy.

Before the biomass feed preparation techniques are discussed, it is important to know their basic characteristics and how these compare with other conventional fuels. Biomass feed normally encompass wood, agro and forestry residues, and municipal solid wastes (MSW). While wood is well understood, MSW, being a product highly dependent on the standard and mode of urban living, is rather complex and beyond the scope of this paper. Accordingly, this paper mainly focuses on the characteristics and processing of numerous species of agro and forestry residues.

Thermochemical characterization of loose biomass

Biomass species, like coal, are characterized in terms of their physico-chemical properties. The physical properties are: shape, size, and bulk density, while chemical properties are composition, heating value, ash constituents, and their slagging properties. In addition,

TABLE 1
Density (specific mass) and (net) calorific value (heat of combustion) of fuels

Types	Density (kg/m³)		Calorific value	
	Real	Apparent	MJ/kg	kcal/kg
Liquefied petroleum gas	560	—	45.3	10820
Gasoline (petrol)	720	—	44.0	10510
Kerosene	806	—	43.1	10270
Diesel oil	850	—	42.7	10200
Fuel oil	961	—	40.1	9580
Coal	1250–1450	—	16.7–33.2	4000–8000
Coke (by-product)	1750–2000	750–1100	29.7	7105
Wood	500–1100	—	16.0–20	4500–5338
Wood charcoal	1400–1700	300–600	29.8	7130
Rice husk (11.4% wet)	1021	101	13.4	3200
Natural gas	—	—	103 m3 at 1013 mbar, 0 °C = 39.36 × 109 J	

Note These values are approximate since the fuels vary in composition, which affects both the density and calorific value

TABLE 2
Typical compositions of solid fuels

Types	Proximate analysis (%)				Ultimate analysis (%)					Heating value (kcal/kg, dry basis)
	Moisture	Volatile matter	Fixed carbon	Ash	Carbon	Hydro-gen	Oxy-gen	Nitro-gen	Sulphur	
Wood										
Oakwood (dry)	—	85.6	13.0	1 4	50.2	6.0	43.3	0.1	—	4622
Pinewood (dry)	—	87.0	12.8	0 7	52.6	7.0	40.2	0.2	—	5338
Peat	56.8	26.0	11.2	6 0	23.1	9.6	59.6	1.3	0.4	4625
Lignite	34.8	28.2	30.8	6.2	42.4	6.7	43 3	0.7	0 7	6110
Coal	3.0–20	16.0–40	40.0–80	3.0–40	60.0–50	3.0–6	3.0–6	1 0–1 5	0.3–4.3	4000–8000
Bagasse	—	80.5	17 0	2 5	48 0	6.0	43.2	0.3	0.1	4430
Coke	0 8	1 4	87 1	10.7	85 0	0.8	1 2	1 3	1.0	7105
Charcoal	12 0	1.9	83 1	3.0	84 0	2 3	10.7	—	—	7130

other parameters necessary to understand their behaviour during combustion are devolatilization characteristics. The comparison of some of the properties of biomass with those of conventional fuels is given in Tables 1 and 2.

Physical properties

Physical properties, such as shape, size, and porosity, indicated by true and apparent density, directly influence the pathways of combustion for biomass. For loose biomass species, bulk densities, which are a function of their particle size distribution and tendency to stay loose or packed in piles, play an equally important role in combustion. These properties determine the surface area per unit volume exposed to flames during combustion, rates of particle heat up and volatiles released, flame stability, extent of particulate emissions, and overall thermodynamic efficiency. Data on bulk densities of some typical loose and compacted materials are given in Table 3.

Calorific values

The normal procedure employed to measure calorific value, by a bomb calorimeter, gives higher heating value (HHV). But what is normally utilized in combustion/gasification systems is the net heating value (NHV). The determination of hydrogen content in biomass is essential to arrive at NHV. By deducting the latent heat of water vapour during combustion from HHV, the net calorific value can be calculated.

Ash content

Of all the constituents of biomass, the variation in ash is significant in loose biomass. It varies from 1.5% in corn cobs to 20–23% in rice husk, compared to 0.5–3% in wood. Based on ash content, various biomass species can be classified into three categories: low ash (1–4%), medium ash (4–8%), and high ash (>8%). This classification, along with the equally important factor of shape categorized as powdery, granular, and straw/stalk type materials, has been compiled and presented in Table 4 (Grover 1995a).

TABLE 3
Bulk densities of typical original and processed biomass materials

Fuel	Grading (kg/m³)	Bulk density
Alfalfa seed straw	Cube: 30 × 30 × 50 mm, moisture: 7%	298
Barley	Cube: 30 × 30 × 50 mm, moisture: 7%	300
Bean straw	Cube: 30 × 30 × 50 mm, moisture: 7%	440
Brown coal	Air-dried lumps	650–780
Charcoal (10% moisture)	Beech	210–230
	Birch	180–200
	Softwood blocks	150–170
	Softwood slabs	130–150
	Mixed: 60% hard/40% soft	170–190
Corn cobs	Moisture: 11%	304
Corn stalks	Cube: 30 × 30 × 50 mm	391
Cotton gin trash	Moisture: 23%	343
Chips	Moisture: 10%	167
Coal	Anthracite	830–900
	Bituminous	770–930
Coke	Hard	380–530
	Soft	360–470
Olive pits	Moisture :10%	567
Peat	Dust	550–620
	Briquettes: 45 × 65 × 60 mm	180–400
Peach pits	Moisture: 11%	474
Prune pits	Moisture: 8%	514
Rice hulls	Cube: 30 × 30 × 50 mm	679
Sawdust	Loose	177
Sawdust	Briquettes: 100 mm long	555
	Diameter: 75 mm	350–400
Straw	Loose	80
	Bales	320
Sunflower straw	Cube: 30 × 30 × 50 mm	203
Wood	Hardwood	330
	Softwood	250
	Mixed: 50/50	290
Walnut shells	Cracked	336
	Pellets: 8 mm	599
Wood blocks	Moisture: 17%	256

Biomass conversion processes

Biomass conversion processes can be classified as physical (briquetting, etc.), biological (biogas recovery), chemical (hydrolysis for chemicals like ethanol recovery), and thermochemical (combustion, gasification, pyrolysis, or liquefaction). This paper is mainly concerned with the feed-processing techniques of biomass for thermochemical processes. As the name indicates, these processes are initiated with heat and take place at elevated temperatures (300 to 1000 °C). These processes are illustrated in Figure 1.

TABLE 4
Classification of biomass based on physical shape and size and in terms of ash content (%)

Ash content	Powdery	Percentage	Coarse/ granular material	Percentage	Stalk-like material	Percentage
Low ash	Eucalyptus sawdust	0.4	Kikar (*Acacia*)	0.6	*Grewia optiva* (Bhimal)	0.32
	Sawdust (saw mill)	1.3	Walnut shell	0.7	Elephant grass (*Miscathus*)	0.4
	—	—	Labakshi	0.75	Khair wood	0.8
	—	—	Amla seeds	1.2	Corn cob	1.2
	—	—	Cedar cones	1.5	Jute stick	1.2
	—	—	Waste from Dabur	1.5	*Vitex negundo*	1.5
	—	—	Pine needle	1.5	*Carissa carandas*	1.6
	—	—	Harid	1.6	Soyabean stalk	1.5
	—	—	Coffee spent	1.8	Sunflower stalk (without spongy part)	1.9
	—	—	Bagasse	1.8	*Adhatoda vasica*	2.0
	—	—	Coconut shell	1.9	Mulberry stick	2.1
	—	—	Khandasari bagasse	2.6	*Artemisia parviflora*	2.3
	—	—	Fibre of green coconut	2.8	Tea bush stem	2.5
	—	—	Subabul leaves	3.6	*Rhus cotinus* (tunga)	3.0
	—	—	Groundnut shell	3.6	Besaram	3.1
	—	—	Tea waste	3.8	Jowar straw	3.1
	—	—	—		Arhar stalk	3.4
	—	—	—		*Lantana camara*	3.5
	—	—	—		*Mallotus phillippensis*	3.7
	—	—	—		Thakal kanda	3.8
Medium ash	—	—	Cherry coffee	4.0	Congress grass (*Parthenium hysterophorus*)	4.2
					Sunflower branch	4.3
	—	—	Tamarind husk	4.2	Gokhru (*Xanthium strumarium*)	4.5
	—	—	Sweet sorghum bagasse	4.2	A grade grass	5.2
	—	—	Coffee chaff	4.6	Chirotha	5.2
	—	—	Cotton shells	4.6	Castor stick	5.4
	—	—	Tannin waste	4.8	Bidens	5.6
	—	—	Waste from Dabur (Bark)	5.1	Dry potato waste	5.8
	—	—	Arecanut shell	5.1	Ragi stick	7.1
	—	—	Coconut coir	5.2	Sweet sorghum	7.4

Contd...

TABLE 4
Contd...

Ash content	Powdery	Percentage	Coarse/ granular material	Percentage	Stalk-like material	Percentage
					stalk	
	—	—	Coffee husk	5.8	—	—
	—	—	Coconut waste (top cover)	6.3	—	—
	—	—	Tea leaves	6.7	—	—
	—	—	Soyabean husk	7.2	—	—
	—	—	Sugarcane leaves	7.7	—	—
	—	—	Bagasse pith	8.0	—	—
High ash	Industrial bamboo dust	9.9	Cover of castor	—	B grade grass	8.8
	Tobacco sawdust	19.1	Oil seeds	9.0	Jowar stalk	9.5
	Fly dust	19.2	Sal seed husk	9.4	*Ageratum conyzoides*	9.5
	Jute dust	19.9	Sunflower	10.1	*C. ciliaris* grass	9.7
	De-oiled bran	28.2	Water hyacinth	10.8	Banmara weed	10.9
	Dal lake weed	48.7	*Mentha piperascens*	13.5	*Ficus*	10.9
	Tobacco dust	49.4	Effluent sludge	14.4	Hybrid napier grass	11.5
			Mustard shell	15.4	Ground paddy straw	15.5
			Senna leaves	17.25	—	—
			Spearmint	18.1	—	—
			Sal seed leaves	19.7	—	—
			Decaffeinated tea waste	19.8	—	—
			Rice husk	22.4	—	—

Integrated biomass technologies for energy and marketable products

These technologies have been identified taking into consideration the level of development in infrastructure and markets for products and energy in developing countries.

Of all the biomass-based thermochemical conversion processes, such as combustion, gasification, liquefaction, and pyrolysis, the last one is the most flexible with the maximum potential. Through this route, we can obtain gases for power generation or for clean burning in boilers, liquid products as industrial raw materials, and solids like char as metallurgical fuel and also as clean domestic fuel, replacing firewood and petroleum products. Further, depending on raw materials used and demand for products, one can vary the pro-

Products of pyrolysis and their uses

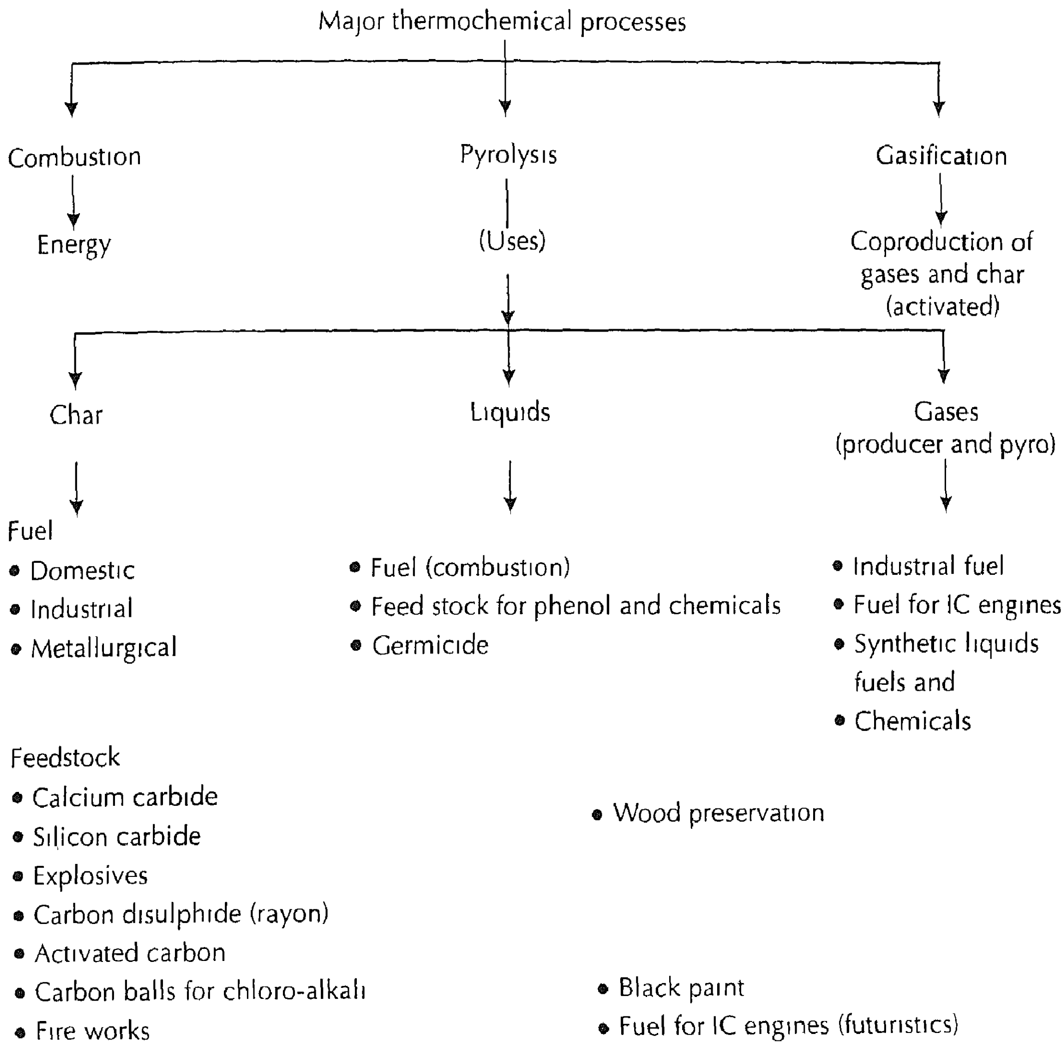


Figure 1. Major thermochemical processes in biomass conversion

portions of these products. The basic concept over-riding the development of these technologies is that, instead of producing useless ash through combustion with its associated disposal problems, the ash should be recovered with varying amounts of carbon. The resulting product can be used as such or briquetted and sold as industrial/domestic fuel. Based on the characteristics of size, ash, and moisture content of biomass, these technologies have been classified into four categories, each one identified to suit a set of biomass species having similar properties.

Category 1 includes those agro-residues which have low ash (<4%) and are available in large sizes of 20 mm and above in diameter. Some of the major species falling into this category are pigeon pea stalks, twigs, lantana, corn cobs, and similar types of woody biomass.

These materials can be gasified in moving-bed gasifiers of downdraft or updraft configurations. The hot gas produced can be clean combusted in boilers with an overall efficiency

of 60 to 70%. The other main advantage of the downdraft unit is that the gas can be used for power production. The gases are cleaned, cooled, and then injected into internal combustion (IC) engines. About 70 to 80% of the diesel in engines can be saved. About 1.3 kg/kWh of woody or 2.0 kg/kWh of non-woody biomass are consumed. A simple version of these gasifiers, which has been accepted for rural electrification, first involves the partial carbonization of biomass and then the use of the char as the feed for the gasifier.

Category 2A includes the agro-residue species under Category 1 and others with low ash but available in comparatively smaller sizes like sawdust, groundnut and walnut shells, jute waste, pine needles, mustard stalks, and similar materials including industrial organic wastes. These are recommended to be fed into gasification-cum-carbonization systems that are suitable for the simultaneous production of gases, and liquid and solid products.

Many types of reactor configurations can be used. One of the promising and already commercialized systems is the inclined grate unit. This system consists of an inclined grate gasifier-cum-carbonization chamber made out of refractory, in which a part of the gases or char is combusted with controlled air to maintain the requisite temperature for conversion. The quantities of char, gases, and liquid can be varied. The typical product distribution is 20% char, 25% liquid, and 55% gases. The char production can be increased even to 40%, but then the amount of gases available is reduced.

Char is sold as such or briquetted to any desired size by well-established technologies. These are used for ferro-alloys, calcium carbide, silicon carbide, and carbon disulphide for rayon industries or sold as such as barbecue fuels. Tar is separated from liquid products and processed into household germicide (popularly known as phenyl) and black paint. Gases, without the separation of tar, can be used as fuel for boilers, and after the removal of tar, for generation of power. Alternatively, the tar-laden gases can be cracked in a separate cracker cum gasifier (Figure 2) The char can also be converted into activated carbon.

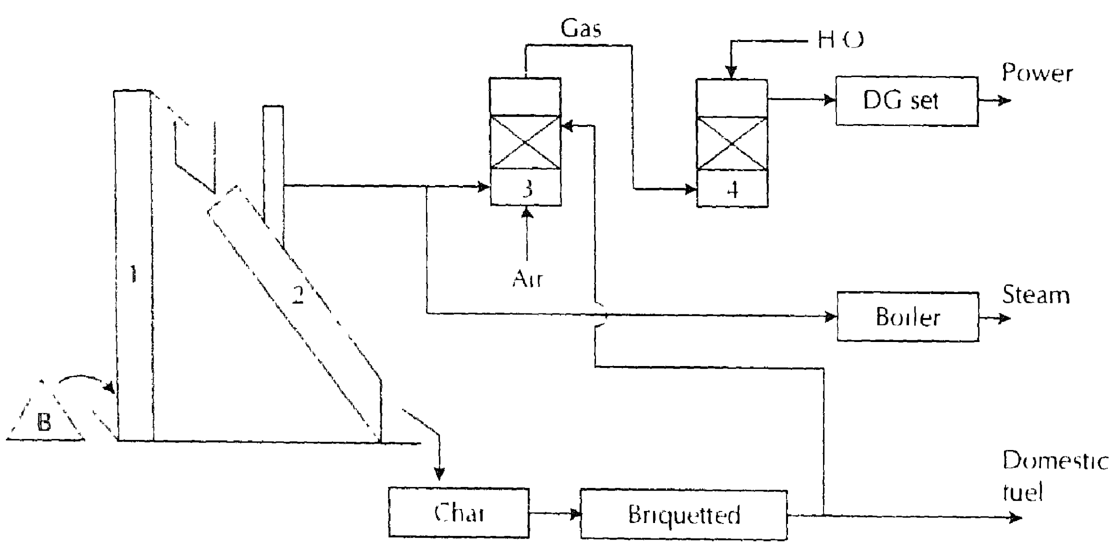


Figure 2. High-ash biomass utilization: clean technology; B: biomass feed; 1: elevator; 2: gasifier; 3: tar cracker (briquettes); 4: gas cooler and cleaner

Under Category 2B, the biomass species included are the same as in Category 2A, except that these are available in wet form, with a 50% moisture content. Additional residues are sugarcane bagasse, coir pith, and others. The technologies suggested are the same as in Category 2A, except that the pyrolyser should have an integrated drier The yield of products is also accordingly different.

Under Category 3, the biomass species having higher ash contents (>4%) have been included. These species are rice straw, soyabean husk, sorghum bagasse, and similar materials. The materials may also have low ash melting points due to presence of p73 potash and other alkali metals in ash. These are normally difficult materials even for combustion in boilers/furnaces and tend to produce more tar.

These materials can best be utilized by low temperatures (about 600 °C) pyrolysis. With or without recovery of tar, the gases can be combusted in boilers and the char (because of high ash content) can be used only as domestic fuel. The char is normally light and comparatively requires more compaction. A pyrolyser configuration similar to those in Category 2 can be employed.

Category 4 accommodates only technologies based on rice husk (RH). RH has been classified into a special category because of its unique properties and is considered as nature's best gift for the recovery of energy and value-added industrial products.

RH contains 65% volatiles, 15% fixed carbon, and 20% ash. Furthermore, rice husk ash (RHA) contains more than 97% finely divided amorphous or reactive/biogenic silica, which is an extremely useful industrial product. But these favourable properties of silica are destroyed by burning RH in boilers.

When RH is subjected to high temperatures (>750 °C), its silica content tends to become crystalline, and a part of this also combines with carbon and finally results as inert black ash. This ash has no use and is even worse than river sand. Disposal of this 30–40% RHA and RH combustion associated particulate emissions are the two main causes of pollution. Gasification systems based on the direct injection of air also generate useless black ash Although the gas obtained after gasification can be used for clean combustion, the pollution problems associated with RHA disposal have not been solved. It is, therefore, imperative that only those technologies be adopted which incorporate the zero pollution concept and also produce value-added products. The products obtainable from rice husk are shown in Figure 3 (Jain *et al.* 1995).

Biomass feed preparation

Except wood, all other biomass species have very low bulk densities. Accordingly, these are inconvenient and uneconomical to handle, store, and transport. Furthermore, the direct use of these materials for energy is associated with inefficient conversion and widespread combustion-related pollution. For efficient and pollution free utilization, it is imperative to process these materials so as to make them convenient fuels. The main feed preparation techniques are sizing, like making wood chips; densification; and carbonization. To carry out the above operations, it is invariably desirable to dry the materials, either naturally in the sun or through mechanical processing.

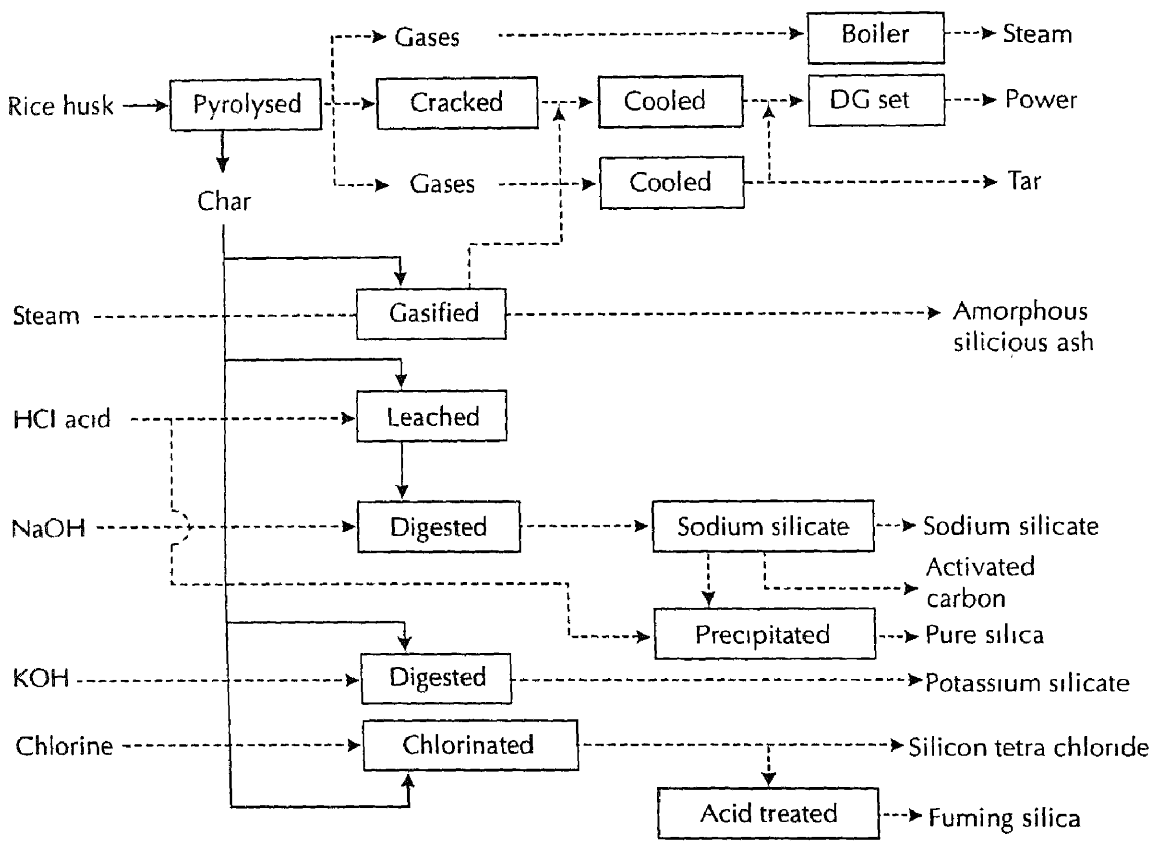


Figure 3. Energy and products from rice husk

Drying

While green wood contains 50–55% moisture, several agro-residues have the same or higher moisture content. These are needed to be dried to extract maximum energy. Table 5 gives the heating values of typical biomass on a wet and dry basis.

Firstly, biomass is dried in the sun up to 20–25% moisture and later by thermal processes. While various systems are employed for drying, the most common practice for chips and powdery materials is to simultaneously convey and dry the materials in entrained bed or flash pneumatic driers

Size reduction

Many biomass residues are cut into smaller sizes for easy handling and efficient combustion. Straw and stalk-type materials are chopped by chaff-cutters into granular materials, either for baling or for easy transportation. Similarly, wood is cut into chips for their efficient use in boilers Size reduction is needed for their use either in fluidized or suspension burning appliances. Though size reduction is necessary for many operations, it is desirable to use the materials in the original form as each conversion operation needs energy, and their handling results in the loss of material.

Table 5
Heating values and moisture content

Biomass residues	Heat value (dry; MJ/kg)	Moisture content (%)	Heat value (wet; MJ/kg)
Wheat straw	17.3	12–22	12.9–14.9
Rice straw	14.6	12–22	10.9–12.6
Bagasse	18.0	40–60	5.7–9.8
Coconut shells	19.1	10–20	14.9–17.0
Beet leaf	15.5	80–90	0.6–1.1

Briquetting technologies[1]

The proven high pressure technologies presently employed for the briquetting of biomass are by the piston or the ram type press and the screw or the extruder type machines (Figure 4). Both the machines give briquettes with a density of 1–1.2 gm/cc and are suitable as industrial solid fuels. The screw-type machine provides briquettes with a concentric hole which gives better combustibility and is a preferred fuel. These briquettes can also be more conveniently deployed in small furnaces and even cookstoves than solid briquettes generated by a ram press.

The most common shapes of briquettes are either circular, hexagonal, or octagonal in cross-section, of 55–75 mm equivalent diameter, and can be cut to any desired length. The shapes of conventional briquettes are shown in Figure 5.

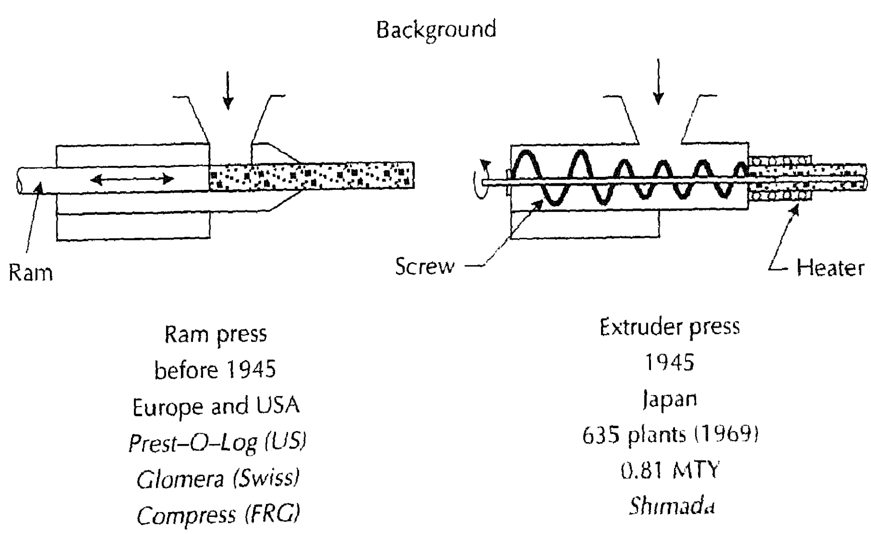


Figure 4. **a** Ram press; **b** Extruder press

[1] From Grover (1995b)

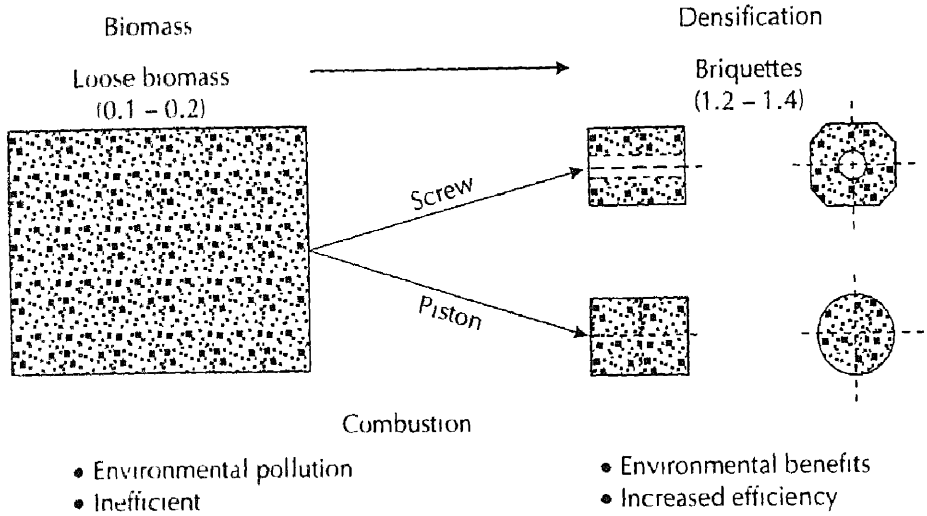


Figure 5. Shapes of conventional briquettes

In addition, to these mechanical presses, hydraulic mode operated machines have also been developed, which can provide briquettes in any form including rectangular shapes of various sizes. But these are not very popular for biomass briquetting.

Ram (piston) press

These machines operate in a discontinuous mode with material being fed into a cylinder, which is then compressed by a piston (ram) into a slightly tapering die The material gets heated due to the friction caused by the forced movement of the compressed briquettes At high pressure (1000 bars) and temperature (250 °C), the lignin content of biomass gets hydrolysed and acts as natural binder. Accordingly, for high pressure briquetting, no external binder is needed. Due to the discontinuous nature of feed compression, the resulting briquette comprises numerous discs pressed together forming a continuous log. Many a time these transverse joints are weak and briquettes readily break in non-uniform lengths.

Because of a reciprocating movement, these presses are driven mechanically by means of massive flywheels via a crankshaft or sometimes operated hydraulically. Output capacities, which are directly related to the diameter of the briquettes, range from 0.25 to 1 tonne/hour from single die machines. Machines with multiple piston-die assemblies are also available.

The machines are robust and function reliably, provided they have been installed properly with dies shaped correctly for the specific raw material. Machines are perfected for sawdust and wood waste but may give mismatch between the feeding rate mechanism and taper sizes of the die for other agro residues (because of different bulk densities), which can lead to many operational problems including the capacity derating of machines.

Maintenance costs for well-engineered plants are reasonable, limited to the replacement of the die after a few hundred hours of operation. However, most of the similar plants manufactured by companies in developing countries have faced numerous mechanical problems due to poor engineering, specially with regard to dimensional tolerances and use of appropriate materials This has resulted in the phasing out of many manufacturers

In India, some manufacturers tried to modify the original European machine by increasing the briquette size so as to increase their output capacity and bring down the production cost, without taking into consideration the basics of material engineering and the process engineering involved in briquetting technology, resulting in their ultimate failure However, in spite of these failures, the credit goes to briquetting technology and its relevance in Indian context that more than 100 machines are working and many more are being installed.

Screw press

An earliest model known as PRES-TO-LOG was developed in the US in the 30s as a low pressure conical screw press. This was further developed into a high pressure machine with externally heated die in Japan during World War II. Another significant feature of this machine was the incorporation of an extension of the screw shaft to act as a guide and provide hollow briquettes. This innovation enhanced the utility of briquettes as domestic fuel. Further, these could be carbonized into high density charcoal fuel which was then the widespread and preferred domestic and industrial fuel in Japan. The model became very successful and the design has been taken up by other manufacturers in Asia and also in Europe. Now, well-engineered screw presses are preferred by users to ram presses.

In this design, material is fed continuously into a screw box which is then forced into a heated die made of heat and abrasive resistant material. The machine runs smoothly and produces more homogeneous and denser briquettes of high quality than those from a ram press.

The die temperature is maintained between 250–300 °C, which is close to the decomposition temperatures of most biomass species resulting in a slight carbonization of the outer surface of briquettes. This imparts hydrophobic properties to the surface endowing the briquettes with longer shelf life.

These machines are made by a number of manufacturers in many countries in Asia in capacities ranging from 60 to 250 kg/hour. European and Japanese models have higher capacities of up to 600 kg/hour.

Unlike in the ram machines, the feed material in screw press is simultaneously mixed, sometimes ground, and then force extruded, accompanied by the emittance of volatiles due to surface carbonization of briquettes. These operations demand additional load and impose severe working conditions on the contact parts of the machine which need to be built in special materials. This aspect is invariably overlooked and not incorporated by many Asian manufacturers, either due to lack of technology or on cost-considerations. This lack of proper engineering has resulted in extensive screw wear and frequent maintenance of machines, leading to numerous failures of these installations.

Well-engineered presses, especially from Japan and Europe, are operating well for a number of years on briquetting of sawdust. However, when these machines were tried on agro-residues, extensive wear of contact parts, in particular the front two flights of screw, was encountered leading to the virtual failure of screw machines Another disadvantage noticed was the extra specific power consumption, a major component of production cost.

In the case of briquetting agro-residues, a substantial part of total power (about 50%) is consumed in feed preparation and p73 material handling system. The conventional feed

preparation system involves: crushing of feed to 8 mm size (not required for coir pith or sawdust) and drying – 12% moisture.

With a view to re-establish the confidence of the entrepreneurs among the developing nations of South-east Asia in this eco-friendly technology, a large-scale project was initiated by the Dutch Government and contracted to the University of Twente and the Indian Institute of Technology, Delhi. The extensive tests, carried out in Delhi on a 400 kg/hour Shimada machine, resulted in solving these problems of excessive wear of screw and higher power consumption. By preheating the dry and crushed agro-residues to 90 °C and the application of a controlled tungsten carbide hard-facing on screws, a consistently improved performance was obtained from the machine.

While working on the most abrasive biomass – RH – the life of screw was increased from 15–20 minutes to 33 hours with 25% increase in production rate. 15.5 tonnes of briquettes were produced before the screw was taken out for hard-facing.

Reduction in specific power consumption was noticed from 70 to 55 kWh/tonne for RH and 30 kWh/tonne for coffee husk. Production rate for coffee husk was obtained as 600 kg/hour from a rated output of 400 kg/hour, an increase of 50%. The cost of screw maintenance, which was prohibitive without preheating, was brought down to Rs 30 per tonne from Rs 150 per tonne.

The latest development of preheating the feed has given productivity and maintenance results on agro-residues comparable to those being obtained in Europe on sawdust, and the technology has now become economical for its adaptation.

Pellet presses

These presses operate by extruding small diameter pellets (10–30 mm) by pressing eccentric rollers inside a large perforated cylindrical or conical die. Originally developed for pelletizing fodder or mineral ores, they have found limited applications in making biomass pellets. These have high capacity of 5–20 tonnes/hour and are highly capital intensive, which are the main deterrents for their application for biomass.

Low-pressure screw presses

Low-pressure machines normally involve a pressure of 5 MPa (50 bars), intermediate pressure machines work in the range of 5–100 MPa, and high-pressure presses generate pressure higher than 100 MPa. Depending upon the pressure applied, the bulk densities of original material can be increased by 2–10 times by briquetting techniques. Normally, low-pressure briquetting needs a binder; however, this is optional for medium-pressure machines and is not required for high-pressure units.

The main advantage of the low-pressure screw press is that the p73 material with 30 to 50% moisture can be compacted. Binders like bentonitic clays, lime molasses, and starch can be used for these machines, and the power consumption is low. For example, a screw extruder being manufactured by Sai Kampangsaen Motors, Thailand, has a capacity of 500 kg/hour and powered by a 5 kW motor driving a screw at 800 rpm The cost of the machine was US $1000 (1993 prices). The cost of the screw was $100 and it needed repairs after 65 tonnes of production. Briquettes produced are normally soft (density = 0.3–0 5) and must be placed by hand on trays used for air drying (Haskoning and Biomass Techno-

logy Group 1989). These machines have limited applications, but in right circumstances, could be a low cost route to briquetting.

Carbonization and briquetting

Partial pyrolysis followed by the briquetting of char using binders is the most suitable and economical route for utilizing most material including coir pith. The objective of pyrolysis is to just destroy the fibre and retain most of the energy in the char. By controlling carbonization parameters, it is possible to retain about 60% of the original energy in char. The char is then mixed with binders such as bentonite, lime, molasses, and non-edible starch (powdered tamarind seeds), and briquetted or pelletized in any desired shape and size and then dried in the sun or in a dryer. In the case of a continuous or semibatch mode of carbonization, hot gases from the kiln can be burned and flue gases used to dry the green briquettes. On a small scale, briquetting can be done manually. Beehive briquettes (Figure 6) with 30–35% potter's clay are recommended for domestic use. Depending upon the location, carbonization can be done in perforated oil drums, troughs, brick/mud kilns of larger capacities, or continuous kilns of any configuration. An inclined grate carbonizer as shown in the figure is recommended. A layout of a carbonized briquetting plant, indicating the type of machinery required is given in Figure 7.

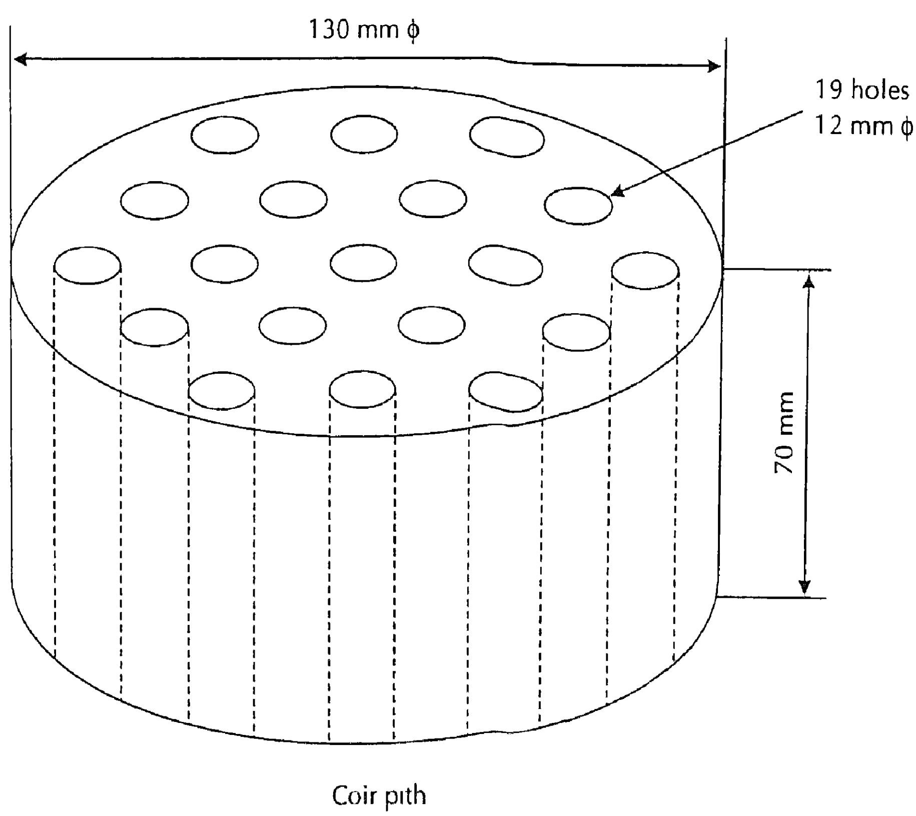


Figure 6. Char beehive briquettes

Broad economics[2]

The installed and operating costs of briquetting and carbonization plants are highly site-specific and also depend upon the type of technology employed and its capacity. The degree of mechanization incorporated in the plant, which differs from plant to plant of the same type and capacity, also influences these cost factors. Further, whether the machine is purchased from the industrialized countries or locally made does determine the different price structure and quality of machines Poorly engineered machines will have more maintenance costs. It is, therefore, recommended that a prefeasibility report should be prepared for each proposed installation before venturing into the briquetting/carbonization of biomass.

Some preliminary cost data are provided to indicate the order of investment and conversion costs based on conditions presently prevailing in India. The costs are given in US dollars (US $1 = Rs 33.3)

1. Screw press briquetting

   - Capacity: 1 tonne/hour with two machines imported from Japan/Europe
   - Yield (based on 10% moisture in feed): 80% of feed
   - Cost of machine: $85 000
   - Cost of plant (fully mechanized with drier and hammer mill): $180 000
   - Cost of production (with 80% capacity utilization 300 days in year): $16.6/tonne

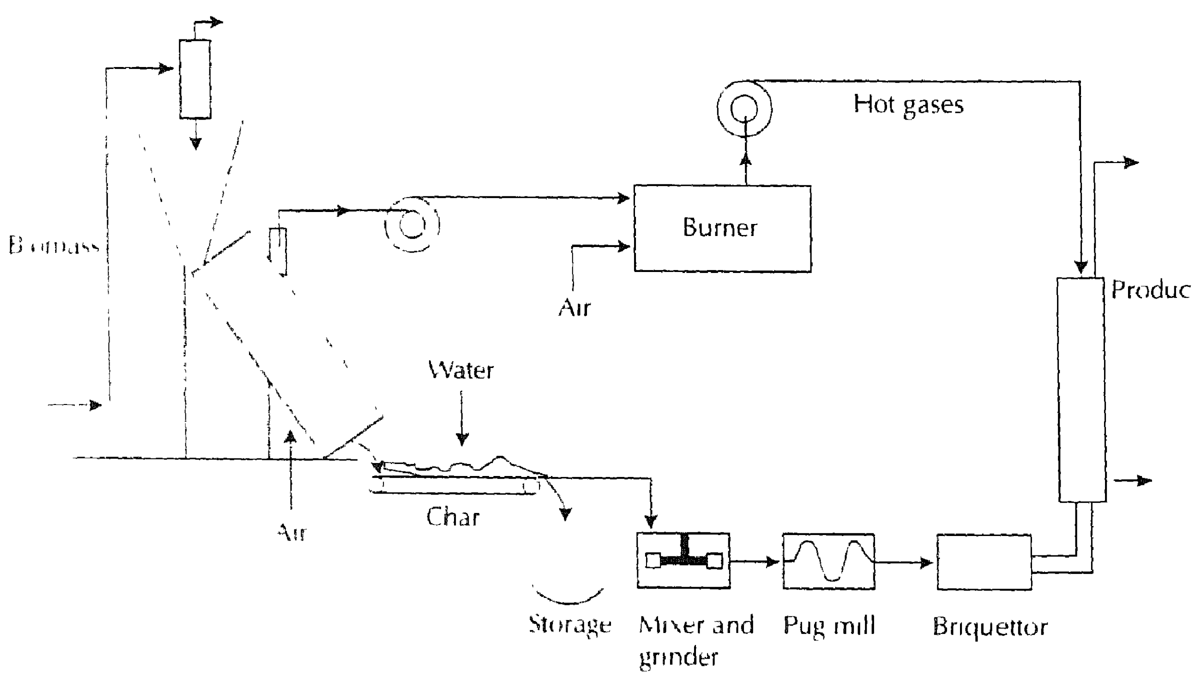


Figure 7. A gas and char system

2. Screw press briquetting (small capacity)

- Capacity: 100 kg/hour with one machine from India
- Yield (based on 10% moisture in feed): 90% of feed
- Cost of machine: $7500
- Cost of plant: $10 000
- Cost of production: $16/tonne

3. Piston press

- Capacity: 1 tonne/hour with two machines from India
- Yield (based on 10% moisture in feed): 90% of feed
- Cost of machines: $60 000
- Cost of plant (with drier and hammer mill): $120 000
- Cost of production (with 60% capacity utilization): $16.5–18

4. Drum carbonization and manual briquetting

- Capacity: 200 kg/two days operation
- Investment (four drums and two moulds): $120
- Yield: 30%
- Cost of production: $6.4/100 kg

5. Brick kiln carbonization and semi-mechanized briquetting

- Capacity: 1 tonne/day
- Cost of plant (includes two kilns and briquettor and drier): $20 000
- Yield (based on 10% moisture): $35–40% of feed
- Direct cost of production: $30–35/tonne

6 Mechanized carbonization and briquetting plant

- Capacity: 5 tonnes/day
- Cost of plant and machinery (includes kiln and briquettor and drier): $100 000
- Yield (10% moisture): 30–40% on feed
- Cost of production: $18–20/tonne

7 Low density briquetting plant

- Capacity (50% moisture): 500 kg/hour with eight hours operation
- Cost of machine: $1000
- Cost of plant. $4000
- Production cost: $16/tonne

Drum charring and briquetting

This is a potential technology which can be propagated as an income-generating activity. The major inputs required are only manpower and the availability of any type of agro-residues, or even MSW, or both. This technology can produce smokeless fuel for the domestic sector and the enterprise can be started as a tiny unit in a decentralized mode. The techno-economic details of a model enterprise based on conditions prevailing in a typical developing country like Myanmar are presented.

Model enterprise (basis: four charring drums)

1. Material balance and expected production
   - Char = 20 kg per drum per batch and two batches per day: 160 kg
   - Clay required (20% of the char): 32 kg
   - Residual moisture in dry briquettes: 10 kg

2. Briquette production per day: 202 kg
   - Number of briquettes (each weighing 400 grams): 500 g
   - Raw materials required (average 30% yield): 540 kg

3. Manpower
   - Labour (full time): 2 persons
   - Labour (part time). 2 persons (as and when required)

4. Cost data
   - Cost of four drums ($20 each drum): $80
   - Cost of two sets of mould: ($10 each mould): $20
   - Miscellaneous hand tools, etc: $20
   - Total. $120

5. Sales (based on prices in Myanmar)
   - Saleable at $0 06 per briquette (6 × 500): $30
   - Less 20% commission and transport charges: $6
   - Net sales $24

6. Operating expenses (eight batches in two days including briquetting)
   - Labour ($1 per person per day): $6
   - Labour (for collection and transportation of raw material at rate of $0.01 per kg $5.4

- Miscellaneous: $1.5
- Total: $12.9 (say 13)

7. Gross profit = $24–13 = $11 in two days

Taking 10 such operations per month, this venture can generate an income of more than US $100 after the payment of wages at the enhanced rate of $1 per day per person. In case, the labour is provided by the family members, the income can be as high as US $224 per month. Since such ventures are site-specific, the project economics should be analysed for each situation.

References

Hall D O, Overend R P (eds.). 1987. *Biomass.* New York: John Wiley & Sons.

Grover P D. 1995b. Resources paper, FAO Workshop on use of loose biomass for stoves, Hanoi, Vietnam, 16–20 October 1995.

Grover P D. 1995a. Technology options of briquetting and carbonization of biomass-coconut industry wastes. Paper presented at UNIDO Inter-regional Workshop on *Use of coconut industry for energy.* Bali Indonesia.

Grover P D. 1995. Biomass energy resource enhancement – techniques and technology. Paper presented at UNIDO symposium on *Development of Biomass Energy in Developing Countries.* Vienna: United Nations Industrial Development Organization.

Jain A *et al* 1995 Energy and Chemicals from Rice husk. *Biomass and Bioenergy* 7(1–6): 285–289

Emrich W. 1985. *Handbook of charcoal making* Boston R Rendel Publishing Corporation.

Guha R *et al.* 1987 Germicidal activities of tar distillates. *Biological Wastes* 21: 93–100.

Bhattacharya S C, Shrestha R M. 1990 *Biocoal Technology and Economics* Bangkok: Asian Institute of Technology

Haskoning and Biomass Technology Group. 1989. Report on Industrial Biomass Energy Conversion for Sri Lanka. Haskoning and Biomass Technology Group.

PYROLYSIS AS A MEANS FOR USING PADDY STRAW AS DOMESTIC FUEL

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Introduction

Biomass is a potential renewable energy source, available in the form of animal and human wastes, and residues from agro crops and forestry. About 660 million tonnes (mt) of agro and forest residues are annually available in India. In terms of energy, these sources represent about 300 mt of coal equivalent. Though a major fraction of biomass residues is burnt in inefficient domestic cookstoves, they still provide about 40% of the total energy consumed in India. Any effort to convert biomass into more useful fuel is a step to conserve the limited resources of fossil fuels.

Of all the agro crops, paddy straw is the most abundantly available as it is not a popular roughage and is used as fodder only where there is a shortage of good quality fodder. In spite of the fact that paddy straw has about the same heating value as wood, it has not found much use as an energy source due to low bulk density and poor combustion characteristics. Domestically, charcoal is preferred to wood, twigs, leaves, and crop stems as a fuel because it burns cleanly and has a higher energy density. Though pyrolysis has been used for obtaining charcoal from wood and woody biomass, very little information is available on pyrolysis as a means for using paddy straw as domestic fuel.

An exploratory study to investigate the pyrolysis of paddy straw in the temperature range of 300–500 °C at atmospheric pressure was carried out. The pyrolytic yields of char, tar, and gases were collected. These outputs were then assessed in terms of a potential on-site fuel system.

Materials and methods

Paddy straw used for pyrolysis was obtained from manually harvested paddy crop leaving 8–10 cm stem in the field so as to avoid picking up dirt from the soil. The straw was chopped and sun-dried for about a week. It was further dried in an oven at 60 °C. The dried straw was then milled in a Willey mill to pass through a 4 mm sieve. The feed material thus prepared was analysed for proximate analysis and heating value to learn its fuel characteristics. The American Society for Testing Materials standard methods for the analysis of coal and coke have been used for analysis as recommended by Ebeling, Jenkins (1984). The results of the above analysis are:

- volatile matter: 71.58% (dry basis);
- ash: 15.05% (dry basis);
- fixed carbon (by difference): 13.37% (dry basis); and
- gross heating value: 16.56 MJ/kg.

The high volatile matter content in paddy straw suggests that it is an excellent material for pyrolysis.

Experimental set-up and procedure

The apparatus used is outlined in Figure 1. A fixed-bed reactor was fabricated to heat the pyrolysis feed material slowly to the desired reaction temperature. It consisted of three

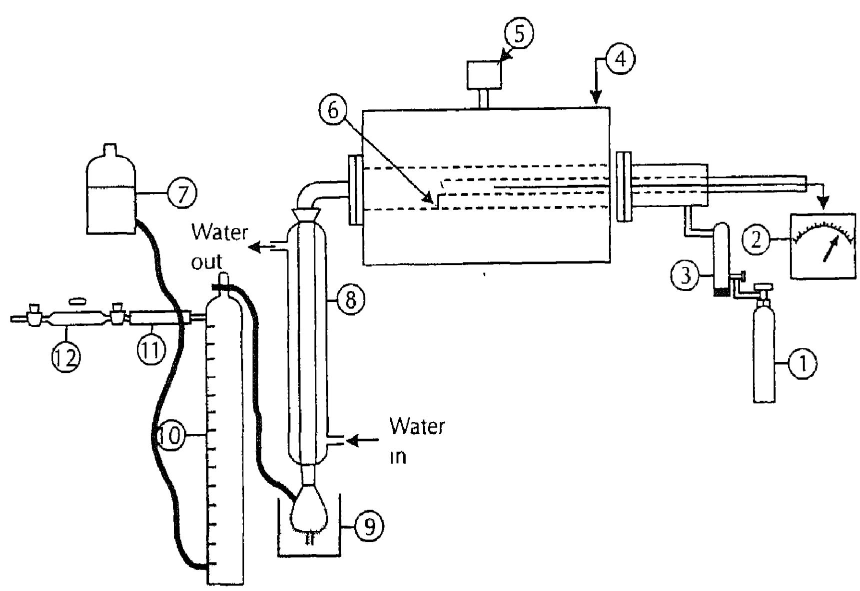


Figure 1. Schematic of the experimental set-up; 1: nitrogen cylinder; 2: temperature indicator; 3: gas rotameter; 4: tubular furnace; 5: temperature controller; 6: sample boat; 7: levelling bottle; 8: condenser; 9: ice trap; 10: graduated gas collecting tube; 11: dryer; 12: gas sampling bottle

main sections: an indirectly heated tube furnace, a nitrogen gas supply system, and a condensate and gas collection system.

A weighed sample of about 2.5 g of the feed was taken in the sample boat and then placed in the tube furnace. The entire system was purged of oxygen (air) by allowing nitrogen to flow through the system for approximately 20 minutes. The feed was then heated by heating the tube furnace, and kept at the desired temperature using a temperature controller. Resistance heating was also carried out on the ends of the tube protruding from the furnace to minimize condensation of tar inside the tube. During heating, the system was kept at approximately atmospheric pressure by the levelling bottle.

At the end of each experiment, the volume of saturated brine displaced in the gas collecting tubes was noted as the volume of pyrolysis gases evolved. The residue in the sample boat gave the char produced. The condensables (tar) were collected in a preweighed small beaker.

The condenser walls, condensate trap, and the tubings were washed with acetone to remove all tar. The acetone was then evaporated from the solution at 62 °C to determine the amount of water and tar accumulated. The residual material was then dried at 105 °C to remove the amount of water contained. The product gases were subjected to gas analysis using a gas chromatograph. Each experimental run was triplicated. The experiments were conducted at temperatures of 300, 400, and 500 °C.

Results and discussion

The variation in the yields of char gases and condensables (tar) at reaction temperatures of 300, 400, and 500 °C is shown in Figure 2. In the temperature range of the above study, the gas yield varied from 11 to 17%, the tar yield varied from 33 to 46%, and the char yield varied from 38 to 50% of dry input feed. The yield of gas and tar increased with the increase in reaction temperature. Hence, the char remaining at the end of each run decreased. The average material balance was about 95%.

Some loss of tar due to the evaporation of its low boiling components such as aromatic compounds in the process of evaporating the acetone could reduce the percentage recovery. However, keeping in view the simplicity of the apparatus, the percentage recovery obtained in the study was satisfactory.

Analysis of the gases showed that the main constituents of the pyrolysis gas were carbon monoxide (40% by volume) and carbon dioxide (53% by volume). Hydrogen and methane constituted about five per cent. The variation in the product gases as the reaction temperature increased is shown in Figure 3.

Gross heating values of the pyrolytic products obtained in the temperature range of the above study are given in Table 1.

The heating value of char decreased with the increase in reaction temperature because char yield at higher reaction temperatures had higher ash content. This was due to the increased release of volatile matter at increased temperatures. Based on these heating values and the yield of the products of pyrolysis, it was found that the char contained 37.8–48.61%, the tar contained 43.36–52.4%, and the gas contained 2.1–4.9% of the heat of paddy straw

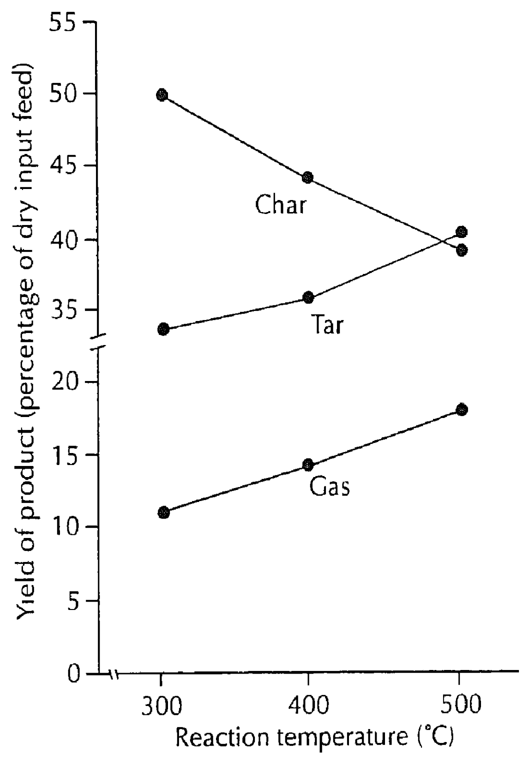


Figure 2. Effect of the reaction temperature on the pyrolytic yield at complete conversion

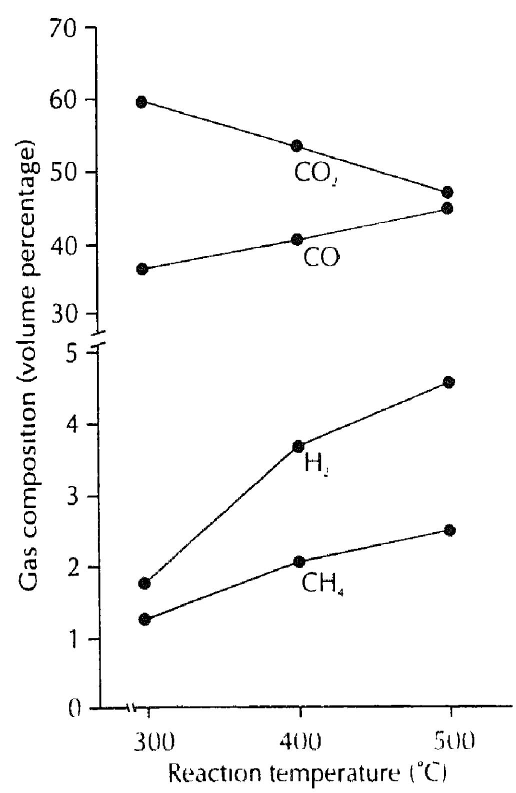


Figure 3. Effect of reaction temperature on the composition of product gases at complete conversion

Table 1
Gross heating values of pyrolytic products (MJ/kg)

Product	Reaction temperature (°C)		
	300	400	500
Char	17.17	16.92	16.46
Tar	21.76	21.76	21.76
Gas	3.19	3.93	4.60

Scope for domestic pyrolyser

The general characteristics of the pyrolysis process at 300 °C result in about 50% reduction in the mass of dry paddy straw while containing 48.6% of the feed energy. Considering that paddy straw contained 15% ash, and that this ash appears as such in the char, the extent of mass reduction can be more if a residue mix of all (available) agricultural crop residues such as cotton stalks, *arhar* stalks, sugarcane shavings, and jute sticks is pyrolysed.

The potential feasibility of the pyrolytic process for using paddy straw as feed material has been worked out below. In the absence of any data on the heat of reaction during pyrolysis of paddy straw, a conservative value of 1600 J/g as in the case of wood (Roberts 1971) heated to temperature not in excess of 320 °C has been assumed.

- Weight of sun-dried paddy straw = 1 kg
- Moisture content = 15%
- Specific heat of straw (assumed) = 0.4 cal/g/°C
- Room temperature = 20 °C
- Energy required to evaporate moisture and heat the feed to the reaction = $0.15 \times 2256 + 0.85 \times 0.4 \times 4.2\ (300 - 20) = 738.24$ kJ ~ 740 kJ
- Thermal efficiency of the process = 50% (assumed)
- Heat required for pyrolysation = 1480 kJ/kg feed
- Heat of reaction of pyrolysis = 1600 kJ/kg

Thus, it is seen that heat of reaction of the pyrolysis is sufficient to raise the temperature of the paddy straw to the reaction temperature even if none of the heat contained in char and tar were to be recovered

In a domestic pyrolyser, the tar would be condensed by passing the hot gases evolved over the emerging char at a temperature slightly above 100 °C. This would enhance the heating value of the char reported in this study. The hot gases can be passed through a condenser to remove water. The dried gases containing carbon monoxide, methane, and hydrogen can be burnt to provide heat for drying the paddy straw, if required, or for getting hot water. The char and tar mixture can be pressed into briquettes or fuel balls without any extra binding agent

References

Roberts A F. 1971. The heat of reaction during pyrolysis of wood. *Combustion and Flame* 17 79–86.

Ebeling J M, Jenkins B M. 1984. Laboratory procedures for the analysis of biomass fuels ASAE Paper 84–3074. St. Joseph, MI: ASAE.

POLLUTION-FREE UTILIZATION OF BIOMASS THROUGH COMBUSTION, CARBONIZATION, AND BRIQUETTING OF RESIDUAL CHAR

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Background

The year 1995 was designated as the 'Year for Substitution of Fuelwood by Other Means' in Myanmar by the government on a national scale. Governmental and non-governmental organizations studied, researched, and disseminated the use of biomass technologies throughout Myanmar. SSIC was also involved in this venture.

In the 'dry zone' areas of Upper Middle Myanmar, use of fuelwood was strictly prohibited and intensive dissemination of use of agro and forestry wastes promoted. Thus, biomass energy utilization and production of a variety of biomass stoves, briquettes, and briquettors became a popular industry.

SSIC's interest in biomass energy was aroused by the designs of the International Rice Research Institute (IRRI) rice husk stoves introduced by Dr Lantin of the United Nations Industrial Development Organization In 1993, after a detailed study of the parts and the operational methods of a briquetting machine from China, SSIC started to build briquettors and produce rice husk briquettes for domestic use. In 1995, when the Myanmar government initiated the exhibition of the use of biomass energy resources in lieu of fuelwood and wood charcoal to the public, SSIC also participated by displaying its products Further information was obtained from the International Workshop on Biomass Briquetting in April 1995, held at the Indian Institute of Technology (IIT), New Delhi, India, during which period, the Tata Energy Research Institute and IIT Delhi's Biomass Conversion Laboratory were also visited.

SSIC's work in biomass combustion

Currently, biomass combustion has only one combustion zone and mainly relies on oxygen. In a two-layer combustion zone, CO_2 can be used as a base to convert to CO This reaction needs heat, and pollution-free clean biomass combustion is based on this technology.

SSIC has conducted research on two separate combustion arrangements of biomass energy. Biomass wastes are ignited in the first combustion and converted to CO. This is then drawn into second combustion zone by passing it through the top of the hot carbon zone, where heat application converts it into CO as producer gas. This producer gas is almost pollution-free and has a high degree of burning capabilities. Residue char can again be made into briquettes for use as fuel.

Layout and process

The diagrammatic layouts of the process are presented in Figures 1, 2, and 3. Any biomass can be ignited in the first combustion chamber and converted into CO_2. A blower draws out this gas through a gas cleaner and stores it in a damper vessel A control valve near the hot carbon zone controls the CO_2, which then could pass through the top of the hot carbon combustion zone where heat converts it into CO as producer gas ready for use by burning. A smokeless, clean blue flame and a high temperature are the end results.

Conclusion

This concept of biomass energy utilization can be of great interest because input biomass can be of any type, including even municipal wastes. Since the disposal of municipal wastes throughout the world is important in order to deal with environmental pollution and health problems, use of such wastes as basic fuel for biomass energy generation can become an important issue in the future.

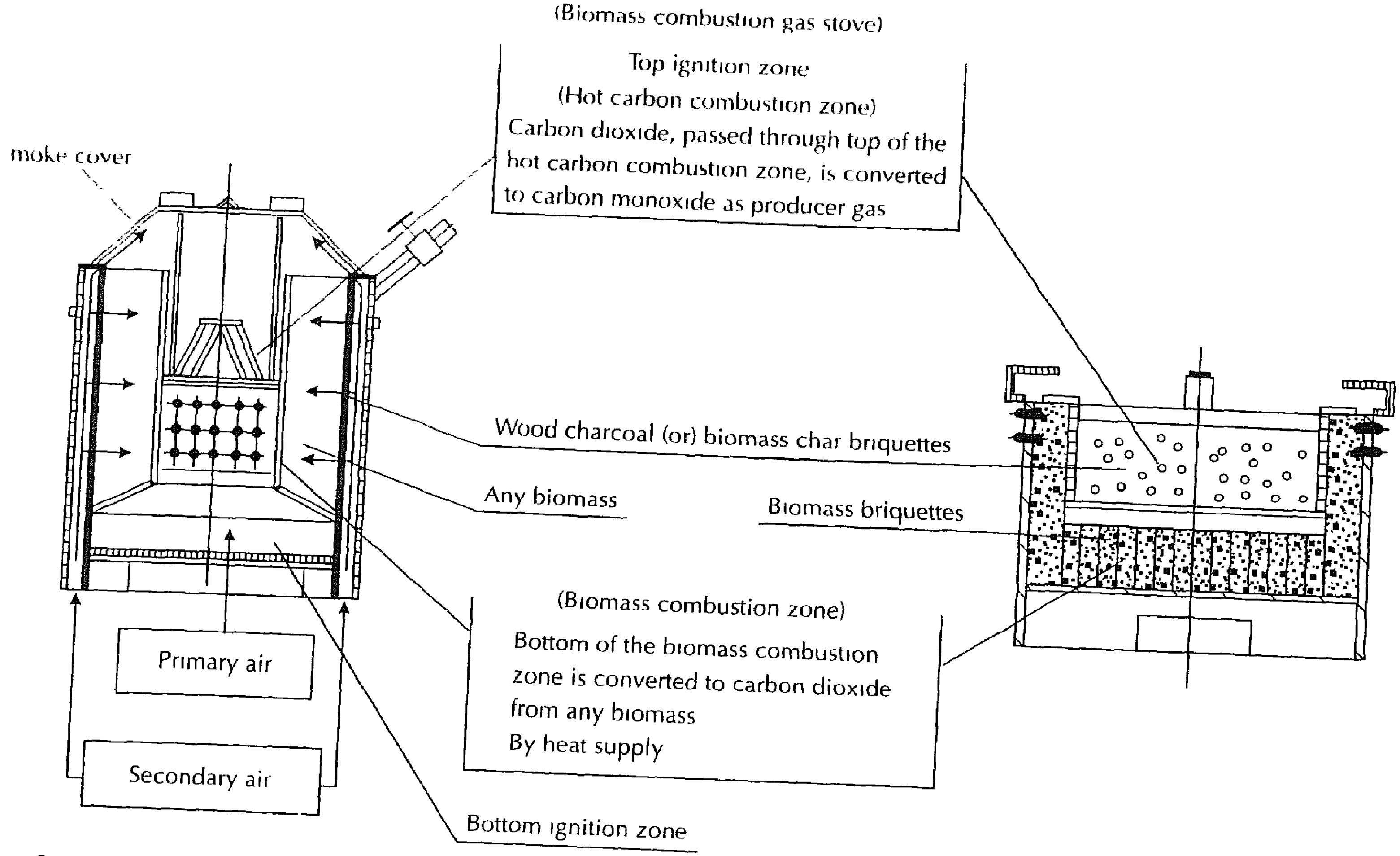


Figure 1. Pollution-free utilization of biomass through combustion, carbonization, and briquetting (basic chemical reactions of this biomass combustion system are: $C + O_2 = CO_2$; $CO_2 + C = 2CO$; $H_2O + C = H_2 + CO$; $CO_2 + H_2 = CO + H_2O$; $C + 2H_2 = CH_4$; etc.)

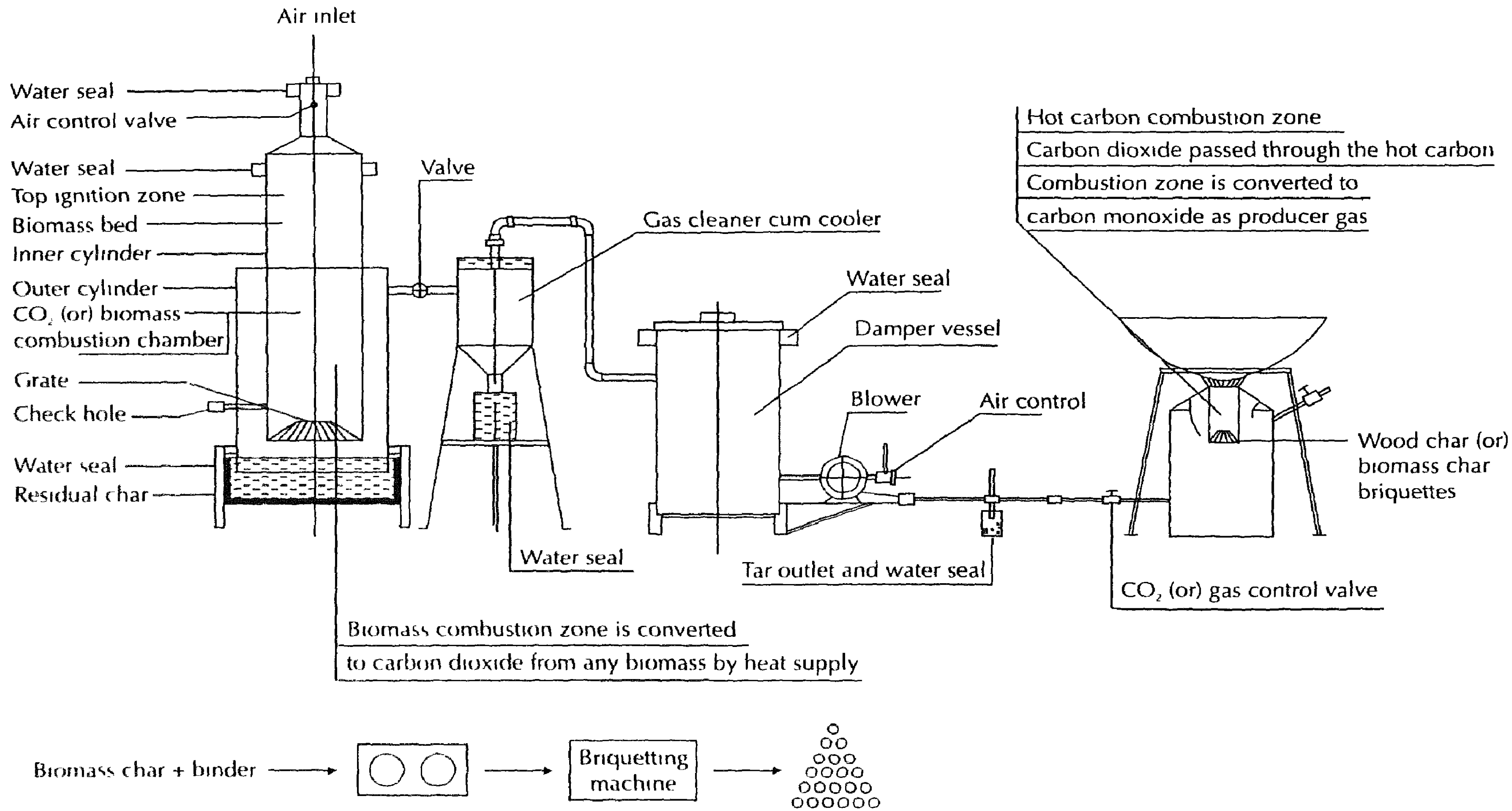


Figure 2. Pollution-free utilization of biomass through combustion, carbonization, and briquetting of residual char for industrial use (R & D stage)

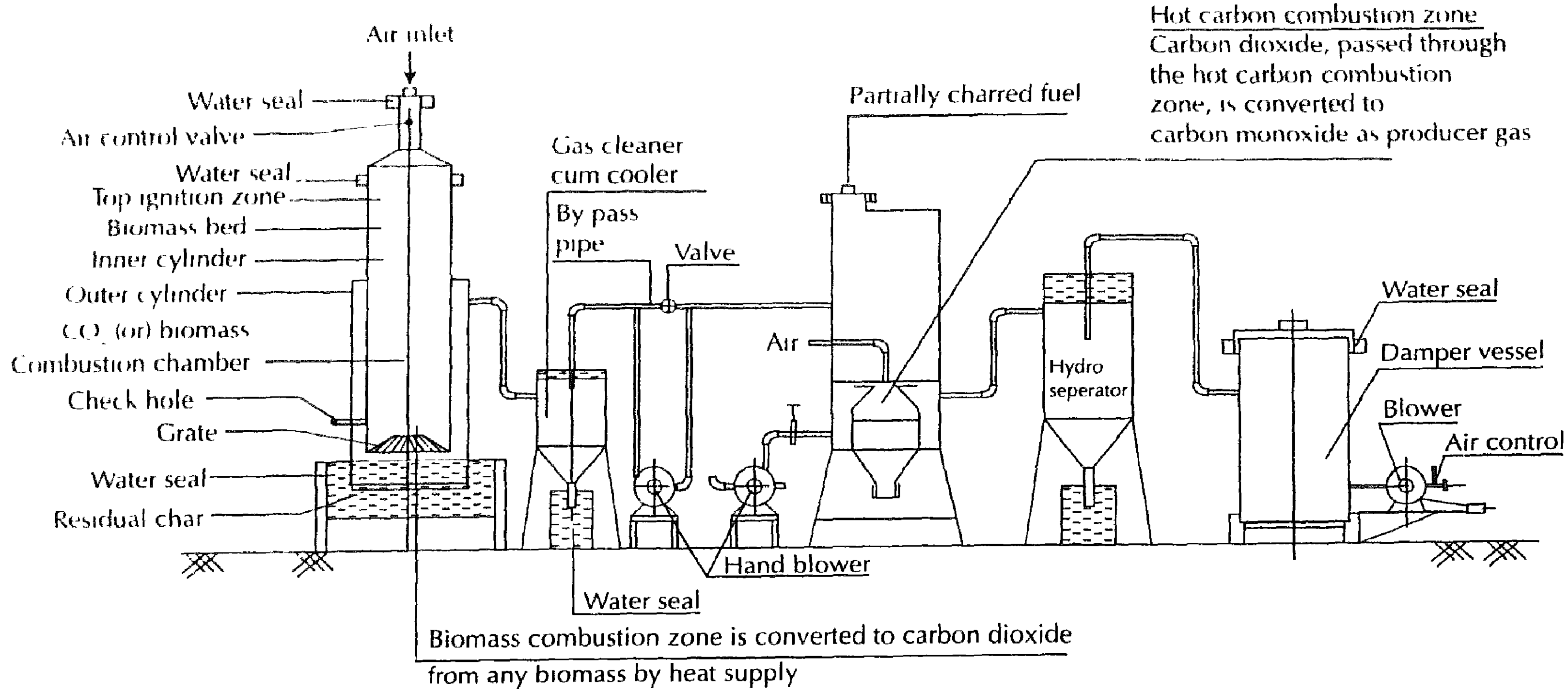


Figure 3. Pollution-free utilization of biomass through combustion, carbonization, and briquetting of residual char (for industrial use)

ANALYSIS AND MODELLING OF THE PYROLYSIS OF BIOMASS: KINETICS AND HEAT TRANSFER IN A SINGLE PARTICLE

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Introduction

Biomass is a traditional renewable source of energy and contributes up to 40% of the total energy consumed in India. However, the crude method adopted in the rural areas for the conversion of biomass into energy has an efficiency of less than 10%, where many valuable organic chemicals are lost, leading to environmental pollution. For more efficient utilization and better environmental protection, gasification of biomass is gaining importance. The gaseous fuel produced can be more efficiently used for production of process heat and running IC engines to be used for agricultural purposes.

Pyrolysis, which precedes combustion and gasification of biomass, plays an important role in these processes and its analysis is expected to provide useful insight into the study of the mechanism of combustion and gasification processes. Mathematical models that can predict the conversion-time relationship with a fair degree of accuracy, are, therefore, very useful.

The phenomena governing the pyrolysis of a single solid particle of biomass are both chemical and physical. Depending on the operating conditions, the process may be controlled either by the chemical or physical phenomena or by both. Bamford, Crank, Malan (1946) were the first who proposed such a mathematical model on the pyrolysis of biomass Several other researchers (Kung 1972; Kansa, Perlee, Chaien 1977; Koufopanos *et al.* 1991) later extended this original model by Bamford (1946). Since biomass is an

extremely heterogeneous substance, a generalized model to describe the pyrolysis process of any biomass is difficult.

The aim of the present work is to provide a rational model for the purpose of describing the pyrolysis of a single biomass particle and predicting the pyrolysis rate and the final mass loss over a wide range of pyrolysis parameters and process conditions. The objectives include quantitative determination of pyrolysis kinetic parameters which are used for the proposed kinetic-heat transfer model so as to understand the interplay between kinetics and heat transfer in the pyrolysis of biomass.

Modelling

Kinetic model[1]

A simple parallel reaction scheme is proposed, representing the primary pyrolysis processes for small biomass particles.

$$\text{Biomass} \begin{cases} \xrightarrow{1 \quad k_1} (\text{volatiles} + \text{gases})_1 \\ \xrightarrow{2 \quad k_2} (\text{char})_1 \end{cases} \qquad (1)$$

The secondary pyrolysis process was neglected. Based on weight loss data, the kinetic rate constants k_1 and k_2 can be evaluated and Arrhenius parameters (frequency factors and activation energies) for the primary pyrolysis process (A_1, E_1, A_2, E_2) are obtained

Kinetic-heat transfer model

The kinetic model proposed for the combined kinetic-heat transfer model for larger biomass particles, a parallel-consecutive reaction scheme which incorporates both primary and secondary pyrolysis processes is presumed.

$$\text{Biomass} \begin{cases} \xrightarrow{1 \quad k_1} (\text{volatiles} + \text{gases})_1 \\ \qquad\qquad + \\ \xrightarrow{2 \quad k_2} (\text{char})_1 \end{cases} \xrightarrow[3]{k_3} (\text{volatiles} + \text{gases})_2 + (\text{char})_2 \qquad (2)$$

For the isothermal reaction, i.e. the residual biomass ($W = B + C_1 + C_2$) can be related to the rate parameters and pyrolysis time by the following equation:

$$W = [\{k_1 - k_3 + \delta \frac{k_2 k_3}{k_1 + k_2}\} \exp\{-(k_1 + k_2)t\} + k_2 (1 - \delta) \exp\{-k_3 t\} +$$

$$\delta k_2 (1 - \frac{k_3}{k_1 + k_2})] / (k_1 + k_2 - k_3) \qquad (3)$$

[1] The nomenclature and Greek letters used in the paper from now on are elaborated in Annexure I

Assuming that heat is transferred inside the solid through conduction only, the energy balance equation can be written in the non-dimensional form as

$$\frac{\partial T}{\partial t} = \frac{1}{R^{\nu}} \frac{\partial}{\partial R} \left(\frac{\alpha}{\alpha_0} R^{\nu} \frac{\partial T}{\partial R}\right) + Q \frac{\partial W}{\partial \tau} \tag{4}$$

$$At\ \tau = 0 \quad T = T_0 = \frac{\theta_0}{\theta_f} \tag{5}$$

$$\tau > 0 \quad at \quad R = 0, \ \frac{\partial T}{\partial R} = 0 \tag{6}$$

$$at \quad R = 1, \quad -\frac{\partial T}{\partial R} = Bi_c(T-1) + Bi_R(T^4 - 1) \tag{7}$$

Where, non-dimensional parameters are

$$R = \frac{r}{r_s}, \ \tau = \frac{k_0 t}{\rho_0 c_{p0} r_s^2} = \frac{\alpha_0 t}{r_s^2}, \ T = \frac{\theta}{\theta_f}, \ Q = \frac{\Delta H \rho_0}{c_{p0} \theta_f \rho}, \ Bi_c = \frac{h r_s}{K}, \ Bi_R = \frac{\varepsilon \sigma \theta_f^3 r_s}{K} \tag{8}$$

The simultaneous solution of the kinetic and heat transfer equations provides the temperature and conversion profiles for the pyrolysis of a solid particle.

The heat transfer model represents a boundary value problem with a non-linear parabolic partial differential equation. The finite volume method was employed for its solution. The transport properties are considered to be a function of temperature and conversion. The correlations used for the evaluation of these properties are presented in Table 1.

The model involves 10 parameters in all, the kinetic parameters A_1, E_1, A_2, E_2, A_3, E_3, and ΔH_1, ΔH_2, W_c, and δ which have to be evaluated. The first four parameters are evaluated based on weight-loss data of fine biomass particles (first set of run), while the remaining

TABLE 1
Values/correlation of properties used in model

Property	Correlation/value
C_p - wood (J/kg-K)	$112 + 4.85T_c$
C_p - char (J/kg-K)	$1003 + 2.09T_c$
K - wood (W/m-K)	$0.13 + 0.0003T_c$
K-char (W/m-K)	$0.08 - 0.0001T_c$
h (W/m^2-K)	$0.322\ (k_0/L)\ (Pr)^{0.333}\ (Re)0.5$
ε	0.95
ρ (kg/m^3)	682

six are evaluated from the second set of experiments (pyrolysis of large-sized biomass particles).

Experimental study

Mass-loss study for sawdust

For evaluating the intrinsic kinetic parameters for the primary pyrolysis reactions, A_1, E_1, A_2, and E_2, an isothermal mass-loss study for the pyrolysis of fine sawdust (−30 + 44 mesh) was carried out. The dried sample placed in an SS wire mesh basket was suspended from a single-pan balance in a tubular reactor in a flowing stream of nitrogen The temperature was maintained between 250–600 °C.

Mass-loss and heat transfer study of wood cylinder

The mass-loss study and measurement of temperature profiles within the wood cylinder was carried out in the same tubular furnace between 290–500 °C. For recording temperatures at various points within the cylinder, thermocouples were embedded at various points within the cylinder. The temperature was monitored with time during the pyrolysis process and recorded in the strip-chart recorders.

Results and discussion

Kinetic model: estimation of primary pyrolysis kinetic parameters

The experimental curves obtained for wood sawdust (fine biomass) under isothermal condition clearly reveal the effect of temperature and reaction time on the pyrolysis rate. As the temperature is raised, the pyrolysis rate rapidly increases and attains the final conversion (95% of the final weight-loss) at a very short time. At a low temperature, the pyrolysis rate is slow, and it attains the final conversion after a long time. Two idealized pyrolysis stages may be distinguished which can be broadly associated with the following phenomena: the first stage signifies the main pyrolysis reaction responsible for most of the weight loss observed and for the production of the char and other pyrolysis products, the second stage is attributed to a slow and continuous devolatilization of the char.

Neglecting the secondary pyrolysis effect for fine particles, the pyrolysis process can be modelled by a suitable parallel reaction scheme. The rate constants k_1 and k_2 were estimated from the mass-loss data at different temperatures using the Levenberg-Marquardt non-linear regression analysis The rate constants were finally plotted against 1/T to obtain A_1, A_2, E_1, and E_2 The values of these parameters are presented in Table 2.

Pyrolysis of large wood cylinder

The pyrolysis of the large wood cylinder is governed by both physical and chemical phenomena So, a combined heat transfer and kinetic model as described earlier is used to predict the pyrolysis behaviour The model parameters A_3, E_3, ΔH_1, ΔH_2, W, and δ were

Table 2
Estimated values of the model parameters

Reaction no	A (s^{-1})	E (J/mol)
1	102.5	11484
2	75.19	11025
3	1×10^6	22000

Note. ΔH_1 = 20 000 J/mol, ΔH_2 = 245 000 J/mol, δ = 1.4, W_c = 0.9

estimated by fitting the above model to the experimental data on weightloss and temperature profiles. The values of the parameters are presented in Table 2 The estimated model parameters are used to predict the pyrolysis behaviour of the large wood biomass particle. The agreement between the theoretical prediction and measured values (weight-loss versus time and temperature profile) is reasonably good. The temperature inside the particle after a certain period of time exceeds the surface temperature and may exceed even the furnace temperature. The exothermicity of the pyrolysis reaction helps to shoot up the temperature The peak observed at the centre is the highest as the rate of heat loss is minimum. The predicted conversion profile reaches a plateau after some time.

Conclusion

The pyrolysis of fine biomass particles can be described by a suitable parallel reaction scheme. The rate constants for pyrolysis are evaluated based on the weight-loss data.

The pyrolysis of large biomass particles, on the other hand, is governed by both physical and chemical effects. A combined kinetic-heat transfer model is proposed to describe the pyrolysis behaviour of large biomass particles. The model parameters are estimated from the experimental data on the pyrolysis of large biomass particles. The combined kinetic-heat transfer model can be fruitfully used for simulation of the pyrolysis of biomass particles

ANNEXURE I
Nomenclature

A_i: frequency factor for the Arrhenius equation, s^{-1}
B: virgin biomass mass fraction
Bi: biot number
C_1, C_2: mass fraction of primary and secondary char
C_p: specific heat (J/kg-K)
E_i: activation energy (kJ/mol)
h: coefficient of convective heat transfer (W/m^2-K)
k_i: reaction rate constant (s^{-1})
K: thermal conductivity (W/m-K)
L: length of the wood cylinder (m)
Pr: Prandtl number
Q: thermicity number
r: radial distance
r_s: radius of the particle (m)
Re: Reynolds number
T: temperature (K)
T_c: temperature (°C)
t: time (s)
W: residual mass fraction

Greek letters
α: thermal diffusivity
δ: deposition
ΔH_i: heat of reaction (J/mol)
ε: emissivity
θ: temperature at a radial distance r (K)
θ_o: initial temperature (K)
θ_f: furnace temperature (K)
ρ: density kg/m^3
σ: Stefan-Boltzman constant
τ: dimensionless time

References

Bamford C H, Crank J, Malan D H. 1946. The combustion of wood *Proceedings of the Cambridge Philosophical Society* 42 166–182

Koufopanos C A, Papavarmakos N, Maschio G, Lucchesi A. 1991 Modelling of the pyrolysis of biomass particles, studies on kinetics, thermal and heat transfer effects. *Canadian Journal of Chemical Engineering* 69 907–915

Kansa E J, Perlee H E, Chaien R F 1977 Mathematical model of wood pyrolysis including internal forced convection *Combustion and Flame* 29. 311–324.

Kung H C 1972 A mathematical model of wood pyrolysis *Combustion and Flame* 18 185–195

SCOPE OF NATIVE BIOFUELS IN THE REPLACEMENT OF DIESEL

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Introduction

Diesel enjoys a prime position for certain energy needs even amidst the rural population. Apart from being a major transportation fuel, diesel is presently used in engines for generating mechanical energy or electrical energy in a decentralized form (TERI 1992) Amidst the frequent power cuts, one can observe diesel generator (DG) sets in shopping complexes and even in residential houses, leave alone the industrial premises where the DG set is a well-accepted alternative for utility. Due to the depleting nature of this resource and due to its non-uniform distribution, a search for an alternative fuel, which can preferably be made available from the local and natural resources, is the need of the hour. Rural farmers, anxious for power for irrigation, look forward to this option in the days of increasing power cuts. Rural people find it difficult to procure diesel as they have to go to the urban outlets to procure it. Biofuels like ethanol and methanol have attracted attention as alternative fuels to diesel due to their similar fuel and combustion properties. However, for a country like India, where the population pressure, combined with the extent of constraints on the cultivable land, makes it essential to use arable land for food production, the option of growing petrocrops yielding ethanol is not an accepted one for years to come. The other alternative is to look for biofuels which can be generated from other crops, which, in turn, does not compete with traditional agriculture for food production. This is possible from plants like *Jatropha* which can be grown in the otherwise unutilized waste lands, with marginal inputs of resources like water and fertilizers (Patil, Singh undated).

Jatropha produces oilseeds that can be crushed to get an oil whose characteristics are very similar to those of diesel, except in its viscosity and flash point. *Jatropha* oil (J oil) can

also be used as feedstock in other industries, e.g., the soap industries (Patil, Singh undated). There should, therefore, be concerted efforts from the government, farmers, and voluntary organizations to cultivate such crops on wastelands available all over the country to generate the biofuels essential for the replacement of diesel.

This paper discusses the results of preliminary investigations on the desirability of replacing diesel with such oils in the existing diesel engine for mechanical and electrical applications. A stove which operates with this fuel for cooking at village levels has also been designed and constructed.

Properties of *Jatropha* as biofuel

The relevant physical and combustion-based properties of J oil as an engine fuel are compared with similar properties of diesel in Table 1.

Some of the results have been taken from available literature, whereas the specific properties mentioned of J oil are measured on a local sample of oil supplied by a voluntary organization called SEVA. The same sample is used in the experiments in the engine later on. The flash point and viscosity values are found to be vastly different from those of diesel

Experiment with diesel engine

The experiment is conducted on a Field Marshal engine of 5 HP capacity (1500 rpm), with minor modifications of the engine carried out primarily to ascertain that J oil does not spoil the performance of the engine These modifications were carried out on: (i) the fuel feed system such as the filter, the fuel injection pump, and the fuel injector; and (ii) the engine injection timing

The engine is run first with only diesel at zero load The content of the fuel supplied to the engine is then converted gradually to a blend of diesel and J oil with the proportion of J oil used in the blend ranging from 10 to 100%. At every stage, the speed in rpm, exhaust temperature, and the time to consume 50 ml of fuel were measured The engine was started with pure diesel and run for about 20 minutes noting down the exhaust tempera-

TABLE 1
Fuel and combustion characteristics of biofuel and diesel

Properties	*Jatropha* oil	Diesel
Specific gravity	0.92	0.82/0.84
Viscosity (kinematic) (s)	0.43	0.025
Flash point (°C)	290.00	50
Calorific value (kcal/kg)	9500 .00	10170
Cetane number	51.00	46–50

ture, rpm, and time for the fuel consumption of 50 cc. The experiment was then repeated by blending diesel and the *Jatropha* component in the ratio of 90:1. Subsequently, the *Jatropha* component in the diesel is steadily increased up to 100% and the engine performance studied. The results are summarized in Table 2.

Preliminary measurements were made based on a fast run for the J oil mode for different loads. The engine was started on the pure J oil mode. No problem was experienced in starting the engine. For this mode, the engine was run for about 15 minutes for a load ranging from 2.5 to 3.0 kW noting the engine speed at about 1500 rpm, the exhaust temperature, and the time in minutes for 50 cc of oil consumption. The optimum conditions of running were observed for a load of 3 kW indicating two minutes for 50 cc consumption with an exhaust temperature of 411 °C.

Performance study in a gasifier on dual-fuel mode

The gasifier used has a 3.75 kW capacity, and is of the Associated Engineering Works (Tanuku, Andhra Pradesh) make. To standardize its performance, the dual-fuel operation was done first with diesel and producer gas for various loads The results are shown in Table 3.

Then the experiment was repeated with J oil replacing diesel for various loads (Table 4). The maximum diesel replacement was at 50% load (75.5%) The speed in rpm does not change drastically in either case for various loads. The pressure drops, at the gasifier outlet and after the cooler, are considerably smaller when oil is used in place of diesel. The gasifier outlet temperature also does not show much variation when diesel is replaced by the oil. However, on the cooler side, the temperature is fairly steady for various loads when J oil is used

TABLE 2
Engine performance using different blends of J oil

Percentage of blend	Exhaust temperature (°C)	Speed (rpm)	Time for 50 cc consumption (minutes)
100% diesel	130	1509	7.38
10% J oil + 90% diesel	128	1508	7.36
20% J oil + 80% diesel	125	1509	7.31
30% J oil + 70% diesel	125	1523	7.21
40% J oil + 60% diesel	124	1525	7.11
50% J oil + 50% diesel	123	1534	7 19
60% J oil + 40% diesel	124	1536	6.59
70% J oil + 30% diesel	123	1544	6.53
80% J oil + 20% diesel	126	1543	6.25
90% J oil + 10% diesel	127	1545	6.13
100% pure J oil	129	1545	5.58

TABLE 3
Performance of gasifier system with diesel–producer gas dual-fuel

Load (%)	kW	Volts	Amps	Time for 50 cc consumption (seconds)		Replacement (%)	Speed (rpm)	Exhaust temperature (°C)	Pressure (mm)		Temperature (°C)	
				Fuel	Dual				P1	P2	T1	T2
0	0.000	250	0.0	406	679	40.2	1550	200	14	13	223	48
10	0.375	250	0.8	358	612	41.5	1541	222	14	15	206	42
20	0.740	250	2.5	308	738	58.2	1535	243	11	21	196	40
30	1.115	250	4.2	267	841	68.2	1521	293	18	22	191	39
40	1.475	250	5.7	230	721	68.1	1513	329	18	14	202	38
50	1.830	250	7.2	220	902	75.5	1515	355	19	23	195	37
60	2.225	250	8 5	184	702	73.7	1508	427	23	25	213	38
70	2.590	250	9.8	169	526	67.8	1500	416	19	28	199	38
80	2.960	250	11.0	154	308	50.0	1496	435	19	28	185	39

Note. Fuel – J oil; P1 – gasifier outlet pressure; P2 – cooler outlet pressure; T1 – gasifier outlet temperature; T2 – cooler outlet temperature.

TABLE 4
Performance of gasifier system with J oil – producer gas dual-fuel

Load (%)	kW	Volts	Amps	Time for 50 cc consumption (seconds)		Replacement (%)	Speed (rpm)	Exhaust temperature (°C)	Pressure (mm)		Temperature (°C)	
				Fuel	Dual				P1	P2	T1	T2
10	0.375	250	0.8	239	318	24.8	1525	266	5	15	224	41
20	0 740	250	2.5	235.5	412	42.9	1524	292	8	12	222	39
30	1.115	250	5.3	221	369	40.1	1569	309	8	16	215	38
40	1.115	250	6.5	199	453	56.0	1552	319	8	14	200	39
50	1 830	250	8.0	185	345	46.3	1533	334	7	15	198	38
60	2.225	250	9.2	173	310	44.1	1540	357	8	15	196	38
70	2.590	250	10.5	153	265	42.2	1535	397	7	15	188	38
80	2 960	250	12.0	139	169	17.5	1520	435	7	15	188	38

Note As in Table 3.

Conclusion

The results of the present preliminary studies indicate that J oil can be substituted for diesel in engines, though the performance level will be ideal only at about 70–80% of the permissible load J oil can also be blended with diesel at different proportions with a fair amount of miscibility. It is, however, clear that *Jatropha* cannot replace diesel altogether, since the time of consumption of 50 cc blended fuel goes on decreasing from the pure diesel mode to the pure J oil mode (from 7 38 to 5.58 minutes). Further, the cost of J oil at Madurai is about Rs 14–16 a litre which is almost double the current price of diesel.

The present study has also indicated that J oil can be used in biomass gasifiers in place of diesel as the starting fuel. The performance characteristics reveal that even though the *Jatropha* fuel replacement by producer gas is less, the overall engine performance is fairly satisfactory. Further experiments using J oil and its blends for studying the exhaust emission characteristics are being carried out. Preliminary results indicate a positive trend from this angle as well. Similar experiments are in progress using yet another vegetable oil called rubber oil.

The encouraging preliminary results suggest the need for more R & D efforts in this direction by chemically pretreating this fuel for bringing down its viscosity and flash point. Simultaneously, efforts should also be made to increase the production of this crop and the oil so that it can economically compete and stride over diesel in the years to come.

References

TERI 1992 *TERI Energy Data Directory & Yearbook 1990/91* Tata Energy Research Institute, New Delhi. pp 66–84.

Patil V, Singh K. Undated *Jatropha curcas – The Wonder Plant.* Hyderabad Food and Agriculture Departments, Government of Andhra Pradesh

COMBUSTION CHARACTERISTICS OF METHANOL FOR FUMIGATED SURFACE IGNITION IC ENGINE

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Introduction

Methanol has been considered as one of the alternative and clean fuels for vehicles, as it leads to reduced air pollution. Therefore, methanol engines are being investigated with regard to reducing exhaust emissions, such as diesel smoke, NO_x, etc. However, for methanol engines installed in heavy duty vehicles, good fuel economy and reliability, like in the diesel engine, are required.

Since methanol has a low cetane rating, which means a poor auto-ignition property, it needs a higher temperature than diesel fuel to obtain auto-ignition (Shi *et al.* 1990). It is difficult to use methanol in a conventional diesel engine without some additional ignition equipment Many investigations have been made on combustion systems for the methanol engine in the diesel engine field (Shi *et al.* 1990; 1993). This paper reports on a study carried out at the Anna University on combustion characteristics of methanol for fumigated surface ignition IC engine

The study

Glow plug arrangement

At the first stage of investigation, the glow plug and fuel injector were arranged in the cylinder head A plate was installed close to and at the upstream side of the glow plug so as to reduce the local air flow speed, and, thereby, reduce the heat loss of the glow plug.

Dual-fuel operation

A direct injection, water-cooled, automotive diesel engine was directly coupled to a Bench make Eddy-Current dynamometer. To facilitate the admission and atomization of methanol and its mixing with air, a suitable carburettor was installed in the air intake system. Main jets of different diameter are used in the carburettor for monitoring the flow of methanol.

Pressure measurement

The measurement of cylinder pressure was made using a Kistler Quartz pressure transducer. The charge output of the transducer, which is proportional to the rate of pressure variation with time, was fed to a Kistler charge amplifier to provide a voltage signal proportional to the cylinder pressure. This pressure signal was superimposed with the crank angle marker signals dynamic injection point marker signals and displayed on a dual beam storage oscilloscope. The oscilloscope was interfaced through a RS 423 Serial Port to the PC-AT 386 computer. The rate of the pressure rise diagram is drawn, from which the delay period is calculated.

Measurement of the dynamic injection point and duration of injection

A Piezo-electric sensor, having a very high frequency response, was used for the determination of the dynamic injection point and the duration of injection. The pulse produced by the pick-up during the period of diesel injection as a result of the movement of the spindle was communicated to the oscilloscope and to the computer.

Crank degree marker

For the measurement of cylinder pressure with respect to the crank position, a crank degree marker and an electromagnetic pick-up were used.

Exhaust smoke measurement system

This exhaust smokemeter (ED 1950 Diesel Exhaust Smokemeter) (ST-100N Type) is based on the filter-reflection system. The exhaust smoke of an engine is sampled as it leaves the muffler. Thus, the pollution rate reading is shown on the pollution meter in terms of the exhaust smoke density.

Test procedure

The performance of the engine was completed with diesel as the base line, and the following parameters were recorded: (i) consumption of inducted and injected fuels, (ii) exhaust gas temperature; (iii) inlet and outlet water temperature; (iv) peak combustion pressure; (v) point of dynamic injection, (vi) ignition point, (vii) combustion pressure curve, crank degree marker curve, and fuel injection pulse curve transferred to personal computer; (viii) glow plug current; and (ix) exhaust smoke density

Dual fuel test

The following experimental runs were carried out with methanol: (i) constant speed and variable load tests; (ii) tests with six degree crank angle advance injection of the injected

fuel; (iii) tests with different glow plug current, and (iv) tests with different carburettor main jet diameter such as Jet 52 (0.52 mm dia), Suzuki Jet (0.72 mm dia), etc.

Results and discussion

A series of tests were carried out to study the effect of glow plug power on specific energy consumption (Figure 1). The results show that the glow plug power required increases as the engine load is reduced. This is obviously due to the lower cylinder temperature and longer delay period under low load conditions. However, the variation of specific energy consumption is only small when the glow plug power exceeds the value required for minimum specific energy consumption. The calculated delay period for methanol is 3–6 milliseconds (ms) more than that of diesel fuel (Figure 2).

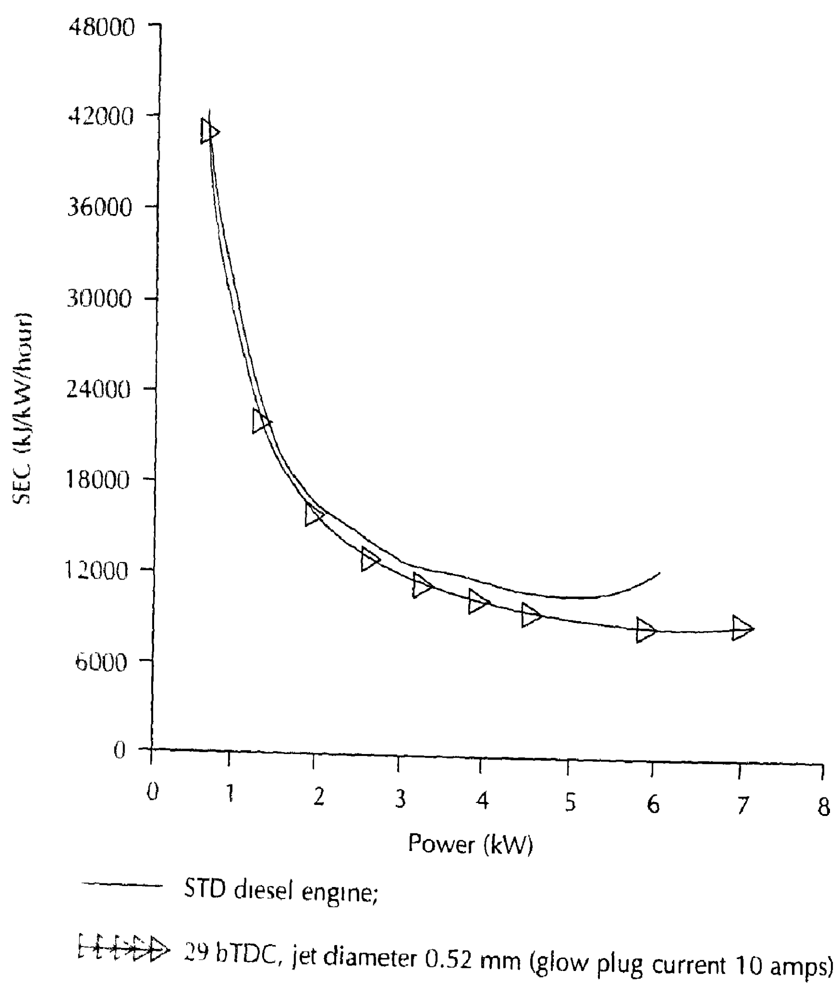


Figure 1. Study of engine power versus specific energy consumption

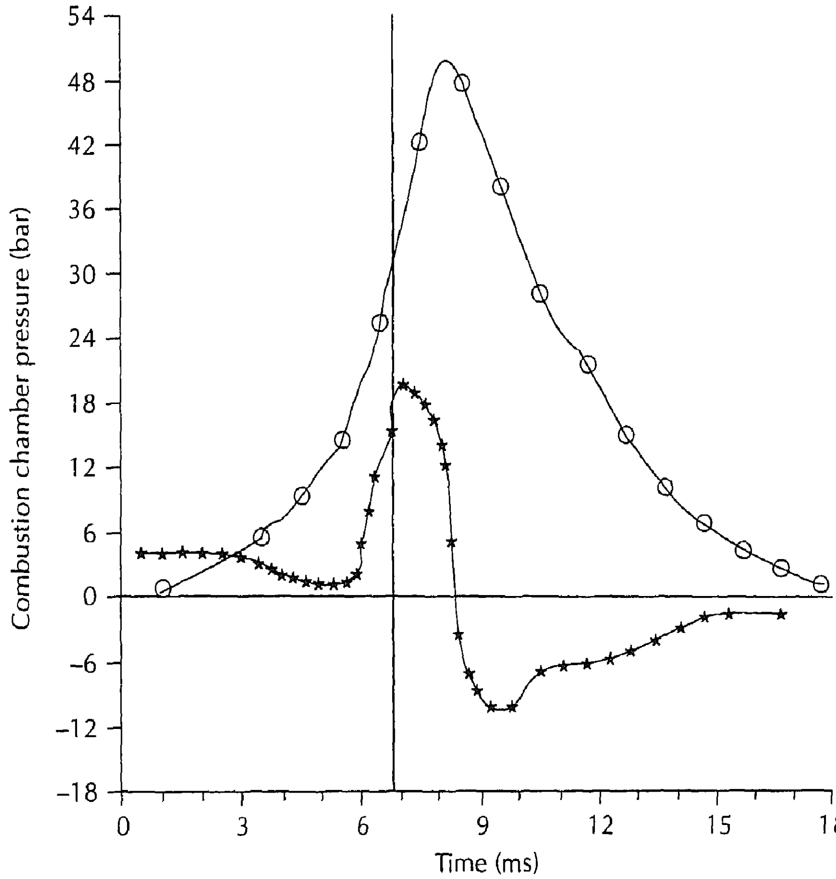


Figure 2. Rate of pressure change load: 24 NM

Brake thermal efficiency

The maximum brake thermal efficiency (BTE) of the diesel engine is 25% at the power output of 3.9 kW/1372 r/min. whilst that of the methanol engine is 32% at the power output of 4.844 kW/1542 r/min. (Figure 3). The BTE and the corresponding power output are increased by 7.43% and 19.9% by using methanol. This improvement in engine performance is mainly due to the high burning rate of methanol and the better utilization of air (Hidino, Suzuki undated; Varde undated; Kajima *et al.* undated, Maurao, Herbstman undated).

References

Shi S X, Fu M L *et al* 1990. An investigation of burning pure methanol by glow plug ignition in a diesel engine. *Journal of Engineering Thermophysics* 2(2)

Shi S X, Fu M L, Yank Zhou Z. 1993. Study on burning pure methanol in DI diesel engines by hot-surface ignition. Tenth International Symposium on Alcohol Fuels 2. Colorado

Kiyoharu Hidino, Takayuki Suzuki. Undated. Development of methanol engine with auto ignition for low NOx emission and better fuel economy. SAE Paper 891842.

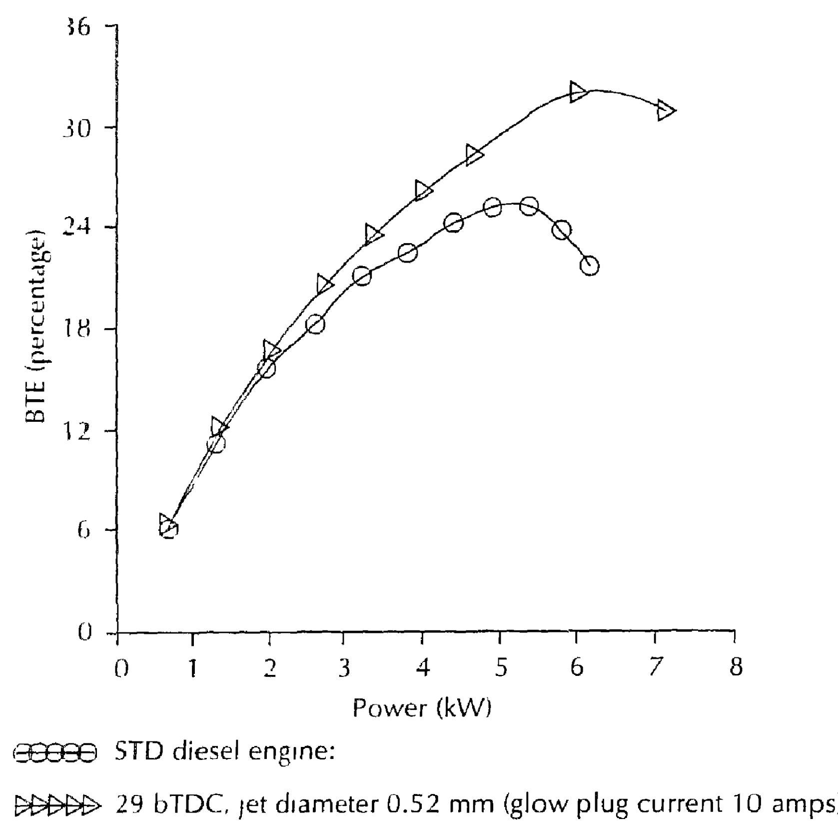


Figure 3. Study of brake thermal efficiency versus brake horse power

Varde K S Undated Compressibility of diesel and methanol fuels of low temperatures. SAE PAPER 890055

Kazuo Kajima, Toshio Hirota, Keiji Yakushiji, Yasunori Iwakiri, Keisuke oda, Yasuhisa Akitsu Undated Effect of reformulated gasoline and methanol on exhaust emissions SAE Paper 912431

Maurao D P, Herbstman A M Undated The properties and performance of modern automotive fuels SAE Paper 861178

Section 3

Biomass gasification

COMBUSTION AND GASIFICATION OF RICE HUSK

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Introduction

India produces paddy to the extent of 80 million tonnes (mt) and produces, thereby, at least 16 mt of rice husk (20% of paddy on weight basis). Taking a moderate 50% utilization figure, 8 mt of rice husk, still is available to be utilized in an efficient manner for energy and power generation and other uses. Needless to say that if the total rice husk produced is available for energy and power generation, it can replace 9.33 mt of coal or 6.4 mt of oil.

The efficient utilization of rice husk would not only lead to a clean environment but also provide valuable fuel, and in addition, its burnt residue ash can be used as an industrial raw material Thus, the efficient utilization of rice husk also opens up a new vista of a host of new industries and employment opportunities.

Utilization of rice husk as a energy and power source is not a new subject. Wherever drying and parboiling of paddy is taking place, the husk is used as an energy source. Its use has increased in recent times. The industrial applications are in rubber mills, dyeing industries, and other industrial furnaces. The rice husk is also used for power generation in the rice mills, though on a very small scale, meeting their requirement wholly or partly The equipment, e.g. furnaces and boilers, has been especially developed and is in use for these applications. Though large-sized power generation systems are not much in use, except may be in one case, most of the existing systems are geared to cater to rice mills of 1–4 tonnes per hour (tph) capacity.

It is not sufficient to develop an efficient combustion system of rice husk; the system could be related to the end uses of the costly residual ash, which has a potential for both

carbon-free residues as well as controlled carbon and silica products. The ash, at present, has practically no use and is just a waste. The technology for utilization of rice husk ash is not a simple one as it requires deep insight into the structure of the rice husk itself; the knowledge of the processes by which various end products like ash cement, refractory material, amorphous silica, sodium silicate, soil conditioners, and use as fertilizer can be achieved through the various combustion processes which include, among others, pyrolysers and gasifiers. Not only this, but details of destructive distillation and fermentation processes of rice husk to produce liquid fuel should also be explored. These liquid fuels can also be fired in the boiler just like oil. It is, therefore, imperative that the technologies of combustion include both processes and hardware to produce energy and power, and which, at the same time, produce a uniform grade of residual ash of various grades like carbon-free as well as different levels of controlled carbon silica mix are required. An optimum economic balance of the energy/residue mix has to be achieved for desired results. Of course, particulate formation and its arrest before its release by the stack should be within the permissible pollution limits. This aspect needs greater emphasis in the present context

Details of research investigations will have to take care of various aspects of rice husk structure, temperature and catalytic effect, optimum energy residue mix, air turbulence flow, oxygen and infra-red induction, proper burner type, optimum design of furnaces and boilers, and accessories, lower capacity steam and gas turbines, silica wear-resistant coatings and materials for fabrication, and, finally, the evaluation of a complete range of carbon-free residual ash as well as controlled carbon silica ash in the development of various industrial products of high value. Studies on economic returns of competitive uses of rice husk are desirable to put its use as fuel in the right perspective.

Husk: the potential source of energy

One-fifth of paddy by weight consists of husk The calorific value (potential heat available) of husk ranges between 2600–3500 kcal per kg depending upon variety and moisture content (Table 1).

Other fuel characteristics have been studied at the School of Energy Studies for Agriculture (SESA), Punjab Agricultural University, Ludhiana and are given in Box 1.

The heating value of paddy husk is 15 5 MJ/kg, which is lower compared to the heating value of wood ranging from 16 to 20 MJ/kg and that of coal from 23 to 26 MJ/kg. Heat-

TABLE 1

Calorific value of rice husk (as obtained from the bomb calorimeter)

Variety	Higher calorific value (kcal/kg)	Lower calorific value (kcal/kg)	Moisture content (%) (wb) (kcal/kg)	Moisture-free high calorific value (kcal/kg)
IR 8	2937 00	2637 29	8.67	3216.13
Patnai 23	3355 43	3044.70	10.38	3744.06
Padma	3105 99	2828.96	6.62	3326.18

Box 1
Characteristics of paddy husk

Physical	
Bulk density (kg/m³)	11u.0
Angle of repose (°)	58.0
EMC at 80% RS (%)	28.4
Thermal	
Calorific value (MJ/kg)	
Higher	15.5
Lower	14.1
Softening temperature of the ash (°C)	1440.0
Melting temperature of the ash (°C)	1650.0
Thermogravimetric analysis was conducted in air atmosphere at a heating rate of 10°/minute to a maximum temperature of 700 °C	
Proximate analysis (%)	
Fixed carbon	12 5
Volatile matter	71 0
Ash	16.5
Elemental analysis (%)	
Carbon	37.8
Hydrogen	5 0
Oxygen	48 4
Nitrogen	0.3
Silica	15.6

ing value indicates its suitability as fuel. Some other properties such as low density, high ash content and silica in the ash, and poor flow properties at high temperatures made it a difficult material to handle in thermo-chemical conversion processes

Factors affecting burning rate of husk

The physical factors that influence the burning rate of husk in a fuel bed are: the variety of husk, moisture content of husk, particle size and presence of fines, rate of air flow through the bed, height of the fuel bed, and furnace design parameters, such as furnace volume, grate area, grate angle, grate specifications, and furnace configuration. Height of the fuel bed, air flow rate, and furnace design parameters can be controlled for better consumption and higher furnace efficiency. Rice husk offers inherent resistance to burning due to high silica content. The silica is highly concentrated in the innermost and outermost surface of the epidermal tissue, thereby enveloping the carbon and inhibiting its reaction with the oxygen Thus, the rate of combustion of husk becomes very erratic and unpredictable towards the end of combustion.

Furnace descriptions

The husk-fired furnaces currently in use are of the conventional inclined step grate type. Although these furnaces have similar design features, no two furnaces are similar. There are

two basic variations in these furnaces, namely, the under-floor level and the above-floor level. In the under-floor type of furnaces, it is possible to install boilers at the floor level. But, the system has ash-removal problems. All the furnaces are based on the same principle of burning the husk over the grate in the chamber but the dimensions, material of construction, size, and the process of utilizing heat and feeding systems are different. The husk is fed at the top of the grate manually with the help of a feeding roller for a screw/pneumatic conveyer. The husk is spread over the inclined grate, and flows down by gravity where the combustion takes place. The size, shape, and number of grates vary in all the furnaces. In some cases, the step-inclined grates are either horizontal or vertical. The walls and roofs of the furnaces are made of refractory bricks. While in certain cases, the roof of the furnace slopes downwards, in others, it slopes upwards. There is no rational approach to differentiate these. However, maximum care is taken to prevent the furnace from cracking

The criteria for deciding the type of wall of the furnace depends upon the manner in which heat is utilized. In the furnace where boilers are used or direct flue gases are utilized, the walls are made up of fire bricks and fire cement with reinforcement from outside. In other cases, a 75 mm thick mild steel sheet is used as the furnace wall, which acts as a heat exchanger. The heat contained in flue gases is utilized in a number of ways, namely, steam production in boilers, direct use of flue gas mixed with air for parboiled paddy drying, heating water for parboiling purposes, and heating of air for drying purposes.

Husk contains about 20% of ash, and as the combustion is not complete in these furnaces, a huge quantity of black ash is collected after burning. The ash is removed intermittently by manual labour. About 10–30% of ash is accumulated under the furnace grate. To collect the rest of the ash, a tunnel is provided at the outlet of the furnace with a flue path which can be more than 6 m long in some cases.

The flue gases are discharged into the atmosphere through a chimney which also helps in creating a natural draft in the system The draft at the exit of the boiler varies from 6 m bar to 250 m bar, and, normally, the height of the chimney is 30 to 35 m.

Furnace performance

The feed rate of husk-fired furnaces varies between 50–1500 kg/hour. The furnaces are constructed to suit the requirements of steam or hot air The combustion efficiency of various furnaces ranges between 32 to 46%, which is on the lower side because of an external combustion chamber, which prevents radiant heat transfer as the bright flame is outside the boiler, and also because of high excess air and extra surface heat losses. The efficiency of these furnaces is also low because of high unburnt carbon in the ash The thermal grate load factor and the thermal volume load factor of the furnace also affect the overall efficiency. These values were found different because of the dimensional variation in the furnaces.

In another study, furnace and boiler efficiencies were determined for a husk-fired furnace system installed in a 2 tonne/hour rice mill (Singh 1991) (The furnace and a thermal grate load of 748 7 MJ/hour m^2 with grate angle of 50 5°.) The thermal volumetric load of furnace space observed was 332 97 MJ/hour m^3 The average velocity of flue in the duct was 1.36 m/second with the mass flow rate of flue gases 0 881 kg/second. The

average velocity of flue in chimney was 1.675 m/second, while the mass flow rate of air was 0.862 kg/second. The flue duct temperature varied between 198–377 °C. Inside furnace temperature varied between 360–971 °C as feed rate increased from 200–400 kg/hour and percentage excess air decreased from 228.75 to 79 76% and air flue ratio decreased from 14.202 to 7.766. The maximum combustion efficiency of 74 04%, furnace efficiency of 57.43%, and boiler efficiency of 74.37% were observed at the 400 kg/hour husk feed rate and at the air flue ratio of 7.766 and percentage excess air of 80%. Boiler efficiency was at normal operating conditions of 9.8 kg/cm^2 and 600 kg/hour water feed rate, corresponding to a husk feed rate, of 400 kg/hour. Overall optimum furnace and boiler efficiency was 42.71%

Furnace limitations

Inclined grate-type furnaces are found to be popular in the rice mills because of the following reasons:

- low capital cost of the furnace;
- simple design and ease of operation;
- ease in its construction; and
- very low maintenance

These positive points force the users to ignore certain limitations that this furnace might offer, namely, (i) the poor burning rate of husk on the grate with the natural draft system; (ii) the large-size chimney requirement to create a sufficient draft to help sustain the burning rate and take the fly ash past the boiler as much as possible and allow it to settle in the flue duct, and (iii) high percentage of carbon in ash Other observations are listed below.

- The combustion of paddy husk is not complete in these furnaces Instead of white ash, black ash is produced This incomplete combustion results in a low burning efficiency of the furnace In some cases, it is low to the extent that the husk produced in the rice mill is not even sufficient to meet the requirements of the furnace in the mill itself
- Ash disposal from the tunnel is also a problem When the tunnel is filled with ash, the ash particles start flying off the chimney into the atmosphere causing pollution. To avoid this pollution, ash has to be removed from the tunnel frequently. This ash, which collects in the tunnel, also causes a low draft, thus reducing the burning efficiency.
- The life of these furnaces is between one to two years, which is very low.
- In the furnaces where flue is directly utilized for drying paddy, the ash is not properly trapped in the arrester but also mixes with paddy grains. This drying of paddy with ash and flue deteriorates the quality of grains.
- Manual feeding is more common than mechanical and pneumatic feeding in the step-grate furnaces In manual feeding, the feed rate is not constant all the time resulting in fluctuations in the boiler
- The grate angle varies from 40–70 °C At higher grate angles, there is a tendency for the rice husk to roll down quickly, resulting in poor combustion At lower grate an-

gles, the blocking of passage occurs, and, as such, there is a need to standardize the grate angle.

- The feeding system on the top portion of the grate needs proper coupling.
- The grate loading and the furnace volume needs to be standardized.
- The flue duct length between the boiler and the chimney varies considerably, and the frequency of cleaning the duct ranges from once a day to once a month.

New design in the furnace system

Efforts have been made to improve the efficiency of the conventional furnace systems and to provide new furnace designs, both by private manufacturers as well as technical research institutions. The six organizations/institutes listed below have developed furnaces utilizing agricultural wastes as fuels.

- The Regional Centre for Extension Service, Modernization of Rice Processing, Annamalai University, Annamalai Nagar, Tamil Nadu.
- The Post Harvest Technology Scheme, College of Agricultural Engineering, Punjabrao Krishi Vidyapeeth, Akola, Maharashtra.
- The Department of Processing and Agricultural Structures, College of Agricultural Engineering, Punjab Agricultural University, Ludhiana, Punjab.
- The Rice Process Engineering Centre, Department of Agricultural Engineering, Indian Institute of Technology, Kharagpur, West Bengal.
- The Department of Agricultural Engineering, College of Technology, G B Pant University of Agriculture and Technology, Pantnagar, Uttar Pradesh.
- M/s Krishi Sewa, Naroda Industrial Township, Naroda, Ahmedabad, Gujarat.

Besides the above organizations, M/s Wanson (India) Ltd, Chinchwad, Pune; MG Industries, Batala, Punjab; the Post Harvest Technology Scheme, Agricultural Engineering Institute, University of Agricultural Sciences, Raichur, Karnataka; and the Food Corporation of India, New Delhi, have also developed furnaces utilizing agricultural wastes as the source of fuel.

Gasification of rice husk

A study by Bhatnagar, Sehgal (1990) indicates that most of the husk is used as boiler furnace fuel in small and medium scale industries. Two major disadvantages observed were: (i) very low thermal efficiency of husk-fired furnaces (28–35%); and (ii) very serious environmental pollution caused due to emissions of carbon monoxide and fly ash through the boiler chimney. In this context, one of the options is to use paddy husk through the gasification route. In the gasification process, paddy husk is first converted into combustible producer gas (PG), which is then used as boiler-furnace fuel.

Gasification is a thermo-chemical conversion process in which biomass reacts in oxygen- air deficient atmosphere to produce a gaseous fuel mixture of carbon monoxide and hydrogen as main combustible gases along with carbon dioxide and nitrogen. Producer gas

is a low thermal value gas (4.5–5.5 MJ/Nm^3), which can be used as supplementary fuel in internal combustion engines and as fuel in furnaces for thermal applications.

The gasification process is carried out in a reactor called the gasifier. Gasifiers can be broadly classified as updraft, downdraft, and fluidized bed types. The gas produced in a downdraft gasifier contains less impurities and is suitable for engine application, whereas the gas from an updraft gasifier is suitable for furnaces because of its higher tar content.

The downdraft gas producer has a concurrent flow of air or gas and the fuel. The Swedish design concept of downdraft gasifiers is widely accepted and used in various research organizations and commercial sectors of developed and developing countries. This gasifier is highly fuel-specific and cannot be used for gasification of paddy husk.

Gasifiers for rice husk

SESA has designed paddy husk based throatless, downdraft gasifiers in the capacity range of 5 and 10 kW. The gas has been extensively used as supplementary fuel in diesel engines for water pumping or for operating an alternator for decentralized electricity production in remote areas

Another gasifier designed and developed at SESA is an updraft gasifier which uses 20 kg of paddy husk in one hour (capacity of the Laboratory Development Unit) The gas produced in this gasifier was found to be rich in tar and considered appropriate as boiler furnace fuel The gasifier was tested keeping the specific gasification rate (kg husk/hour/m^2 of reactor dia) and the moisture content of paddy husk as variable parameters. On the basis of the results obtained, a 200 kg/hour capacity updraft gasifier was designed and developed to meet the energy requirement of a 1 tonne/hour capacity paddy parboiling plant in a rice mill. A PG burner was also developed. The complete system comprising the gasifier–burner was installed in a rice mill. The operational results of these gasifiers are discussed below.

Open core throatless gasifier

It was experienced that crop residues having a high ash content, such as paddy husk and groundnut shell, could not be gasified in the Imbert type (it has an inverted truncated cone type reactor) gasifier design Throatless downdraft gasifiers of capacities 5 and 10 kW were, therefore, designed and fabricated at SESA.

Gasifier design

The gasifier reactor consists of two concentric cylinders; the inner cylinder acting as reactor, and the outer cylinder, called containment tube, works as the heat exchanger. The reactor and containment tube are flanged from the top with asbestos packing to prevent gas leakage The bottom of the outer cylinder is water-sealed with a circular pan attached to it. Four turn buckles are used to engage and disengage the water sealing pan The reactor length is kept smaller than the containment tube to provide adequate space to pass the gas from the reactor bottom into the containment tube The grate, made from a 20 mesh stainless steel wire mesh, is fitted close to the bottom of the reactor. This grate is supported on

a circular mild steal (MS) ring with the help of four screws. The MS ring is attached to a stand of MS rods which rests on the water sealing pan.

The top of the reactor is open. In the reactor, the fire zone is formed at the interface of char and husk. The fire zone keeps on moving up during gasifier operations. Reduction reactions take place below the fire zone whereas pyrolysis and drying take place, in that sequence, above the fire zone.

Gas cooling and cleaning unit

The gasifier is connected to a gas cleaning and cooling unit. The gas cleaning train includes a water scrubber and a dry packed filter housed in one cylinder. The lower half of the cylinder is packed with wood charcoal. It has a gas inlet near the bottom and water inlet from the centre through a perforated copper pipe coil for water spraying. Water is taken out from the outlet pipe connected to the centre of the bottom lid of scrubber. The length of the water outlet pipe is adjusted to take out the water when the whole system is under suction developed by the engine. The upper half of the cylinder is packed with small pieces of maize cobs supported on a wire mesh as a dry filter. On the top of the dry filter, a circular sheet of foam is fitted to arrest any leftover particulate matter. The gas exit is from the top.

Gasifier-engine operation

The gas exit from the gas cleaning unit is connected to the air intake manifold of the engine. In the air intake manifold of the engine, an additional gas intake pipe was connected along with the air intake pipe to a separate mixer chamber. No other modification in the diesel engine is needed.

The gasifier is operated using a hand blower and, when good quality gas starts coming in, the gas is diverted to the engine which is already working on diesel. This automatically cuts down the diesel consumption; however, some minor adjustment in the engine governor is made to bring the engine speed to rated value. This reduces the diesel consumption to about 75%.

Results

Performance characteristics of the SESA 5 kW throatless gasifier connected to an engine water pumping set and 10 kW connected to an engine generator were observed and reported in Table 2 Each system comprising the gasifier and engine pumping set/generator was operated for more than 250 hours. Typical values of producer gas composition and its lower heating value, diesel replacement, specific paddy husk consumption, and temperatures at various points in the system are tabulated. The operation of the gasifier engine system was highly satisfactory and smooth.

The maintenance schedule of the throatless rice husk gasifier on the basis of 250 hours operation is given below.

- After 35 hours. replacement of maize cobs in dry filter
- After 100 hours cleaning of gasifier and scrubber pipe fittings, replacement of char in the filter, and cleaning of water spray nozzles of the filter.

TABLE 2
Performance characteristics of throatless gasifier-engine pumping set/genset system at full load

Producer gas composition (volume %)	
Hydrogen	12.2
Carbon monoxide	19 8
Carbon dioxide	12 4
Methane	3.0
Nitrogen	53.5
Lower heating value of gas (MJ/Nm³)	4.4
Engine speed (rpm)	1500 0
Diesel replacement (%)	75 0
Specific paddy husk consumption (kg/h/kW)	6.5
Hot gas temperature (°C)	250.0–280
Inlet temperature at filter (°C)	90.0–110
Outlet temperature from filter (°C)	35.0–40
Engine exhaust temperature (°C)	350.0–380

SPRERI has developed a 3.5 kW gasifier for diesel engine pumpset/genset operation and a 20 kW gasifier system for power generation in a rice mill. Both the gasifiers are of the open core, downdraft type systems, and operate on paddy husk as fuel

The 3 5 kW gasifier system saves 70% diesel at 80% system load with a rice husk consumption of 7 kg/hour The 20 kW gasifier system saves 60% diesel at 80% system load and consumes 30 kg/hour

Updraft gasifier

A laboratory development unit (LDU) was designed and developed with a capacity of 20 kg/hour. The LDU was tested keeping specific gasification rate and moisture as variable parameters.

On the basis of the results obtained from the LDU, a 200 kg/hour capacity gasifier was designed and fabricated by SESA The objective of maintaining this capacity was to meet the energy requirement of a 1 tph capacity paddy parboiling plant of a rice mill.

Reactor

The gasifier reactor has an inside diameter of 91 5 cm with a 10 cm thick fire brick lining along the periphery The holding capacity of the gasifier is about 65 kg of rice husk at 10% moisture The height of the gasifier is 1.2 m. A check port is provided in the reactor The gas exit from the gasifier is from the top of the reactor A firing port is provided in the reactor above the grate and manhole in the top cover of the gasifier for feeding the rice husk A provision has been made to install an automatic feeding system in the gasifier with a star feeder to be operated with a variable speed drive

Grate

An eccentric rotary grate consisting of five plates and having a design capacity of 0.75 kg of ash removal has been fabricated and fitted at the bottom end of the reactor. The design

speed of the grate is 3 rpm. The grate is connected to a 1 hp, three-phase electric motor and a speed reduction gear system so that the grate speed is 3–4 rpm.

Ash hopper

A double wall ash residue hopper, with an ash-holding capacity of 10 kg residue/ash produced from rice husk, is fitted at the bottom of the reactor. Fresh air, entering at the bottom of the jacket between inner and outer walls of the ash hopper, is preheated by the hot ash falling from the reactor.

PG burners

Three laboratory scale PG burners were designed, developed, and tested. For testing purposes, PG from a 25 Nm^3/hour capacity downdraft gasifier was used. Flame temperature, quality of air and gas mixing, flame length, etc., were observed. On the basis of results obtained, the gas burner for the 200 kg/hour capacity gasifier was designed and fabricated.

Gasifier performance in a rice mill

The gasifier burner was installed in a rice mill. The rice mill has 1 tph capacity paddy parboiling plant The boiler has an opening of 25 cm diameter at the bottom in addition to the flue gas inlet from the husk-fired furnace. This opening was connected to the producer gas burner for operating the boiler with the gasifier The boiler furnace data of the rice mill are given below

- Fuel paddy husk
- Grate: inclined grate furnace
- Angle of inclination: 57°
- Grate loading: 52.5 kg/m^2/h
- Boiler type: shell and tube (vertical)
- Capacity: 1 tph
- Heating surface: 59 54 m^2

The heating value of the PG was computed by the gas composition. The average gas composition of one run is given below.

- Carbon monoxide: 20.5%
- Carbon dioxide: 11.3%
- Hydrogen. 10.2%
- Methane. 2.5%
- Oxygen 0.2%

The lower heating value of the gas was 4.2 MJ/Nm^3 The gasification efficiency (percentage of input energy to the gasifier converted into combustible gas) was calculated at 70% for one batch.

Table 3 gives the furnace boiler performance data and Table 4 provides data on the gasifier boiler operation

TABLE 3
Furnace boiler performance evaluation

Husk feed rate (kg/hour)	280.0
Steam production (kg/hour)	450.0
Pressure (kg/cm^2)	12.0
Combustion efficiency (%)	79.0
Furnace efficiency (%)	49 0
Boiler efficiency (%)	83.0
Overall efficiency (%)	32.0
Exhaust gas analysis (volume percentage)	
Carbon monoxide	1.8
Carbon dioxide	12.5
Hydrogen	1.2
Nitrogen	76.5
Oxygen	7.4

SPRERI has also developed an updraft type, paddy husk fuel based gasifier system, which has a double conical biomass hopper, a stationary grate with rotating scraper, air disembustion unit, ash pit, 1.5 kW (2 hp) electric motor blower, and an air swirling type industrial PG burner. It has a thermal power range of 10 000 to 50 000 kcal/hour and overall efficiency of 55% The unit produces 100 kg/hour of steam at a pressure of 7 kg/cm^2. Three such units can meet the steam parboiling requirement of a 1 tph rice mill.

Conclusion

Paddy husk has become an important source of energy Use of paddy husk as fuel in rice mill grate type furnaces and boilers has become common in some states Gasifier use in rice mill boilers operation is still to be introduced. Large-size paddy husk based gasifiers and pyrolyser systems of capacity 100 kW and above are not yet available in the country.

However, the grate type and husk-fired furnaces need certain improvements. These are listed below

- The design of grate type furnaces for energy and power to be standardized for a rice mill having a parboiling unit and generating power.
- Need to be designed for maximum combustion efficiency.
- Plant-scale trials of furnaces developed at various R & D institutions must be conducted.
- Development of standard procedures and equipment for testing furnace performance for rice mills and similar agro-industrial units is essential
- The potential of rice husk as a diversified fuel for thermal and mechanical applications through gasification route needs to be looked into.
- Throatless gasifiers need to be developed in the capacity range of 5 and 10 kW, which, when operating on rice husk, can produce gas that makes the smooth and

TABLE 4
Gasifier boiler performance evaluation

Husk feed rate (kg/hour)	200 0
Gas heating value (MJ/Nm³)	4.5
Steam production (kg/hour)	500.0
Pressure (kg/cm²)	12.0
Gasifier efficiency (%)	70 0
Boiler efficiency (%)	80.0
Overall efficiency (%)	56.0
Exhaust gas analysis (volume percentage)	
Carbon monoxide	—[a]
Carbon dioxide	14.0
Hydrogen	—[a]
Nitrogen	78.0
Oxygen	6.0
Producer gas analysis (volume percentage)	
Carbon monoxide	20.5
Carbon dioxide	11.3
Hydrogen	10 2
Nitrogen	2.5
Oxygen	0 2

[a]values could not be determined on the gas chromatograph because of very low concentration gas composition.

satisfactory running of a diesel engine possible, replacing about 75% diesel, and gives a specific husk consumption of about 1 4 kg/kWh.

- The operation of updraft gasifier coupled to a boiler furnace was highly encouraging and resulted in much better thermal efficiencies The emission from the boiler chimney was relatively clean with no fly ash. This aspect, however, need more detailed analytical study,
- The husk-fired large-size gasifier and pyrolyser systems having capacities above 100 kW are not available in the country. Fluidized bed gasifiers need special attention
- The development of a cleaning and cooling train is essential, to provide minimum or no tar load and other impurities for high-speed diesel (HSD) engine operation and gas turbine operation.
- A gas turbine for 100–250 kW capacity gasifier operation needs to be developed and introduced in power generation.

References

Arora B K 1976 Combustion efficiency of a jet type paddy husk burner. MTech, Thesis. Ludhiana Punjab Agricultural University, Department of Processing and Agricultural Structures

Arora B K, Srivastava A K, Bains D P S, Maheshwari R C, Singh H. 1986 *Performance evaluation of Rice Husk fired furnace system* New Delhi National Productivity Council (in collaboration with the Central Institute of Agricultural Engineering).

Bhatnagar A P, Sehgal V K. 1990 Biomass as a fuel and combustion furnaces *Book of Abstracts. International Symposium on 'Application and Management of Energy in Agriculture – The Role of Biomass Fuels.* 21–23 May. Indian Institute of Technology, New Delhi

Bisht B S 1979. *Review of furnace utilizing agricultural wastes as the source of fuel* Project Report No. PH/B/78/2 Bhopal· Central Institute of Agricultural Engineering

Jain A K, Bhatnagar A P, Singh J 1991 Performance evaluation of paddy husk gasifier boiler units. *In* GEDA (ed.) *Proceedings of Third National Meet on Recent Advances in Biomass Gasification Technology.* pp C-5; 1–6. Vadodara: Gujarat Energy Development Agency, 28–29 November

Jain A K, Bhatnagar A P 1990. Gasifiers research at Punjab Agricultural University *International Symposium on Application and Management of Energy in Agriculture – the Role of Biomass Fuels* New Delhi: Indian Institute of Technology May 21–23

Pathak B S, Jain A R. 1986. *Characteristics of Crop Residues* **16**(1): 27–35.

Patil K N, Rao C S. 1993 *Proceedings of NSE Convention* pp 255–257 Vadodara

Singh A P. 1991. Effect of design parameters on the performance of a grate type husk fired furnace. MTech Thesis. Ludhiana Punjab Agricultural University, Department of Processing and Agricultural Structures

Smith M L, Stinson K W 1962. *Fuels and Combustion* 7 267–273

SPRERI 1995 *Profile of Technologies* pp 25 and 28

BIOMASS GASIFIERS: A BOON TO SEMI-ARID AGRICULTURE

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Biomass energy for irrigation in Karnataka

In drought-prone, semi-arid Karnataka, access to reliable irrigation sources spells the difference between subsistence and progress. Large yield deficits occur due to frequent or prolonged moisture stress periods during crop growth. Rainfed farming is widespread and leads to raising low-yielding, drought-tolerant crops such as *ragi*, *bajra*, and cowpea with concomitant low cash returns and low potential for development. Investment costs for borewells with pumps energized by rural grids are out of reach of small and marginal farmers. Avenues for enhancing agricultural incomes are, therefore, limited. Even to large farmers capable of investing in borewells, lack of assured power limits the acreage under irrigation to less than 1 ha per pump (3.7 kW pumps on grid). A locally controlled biomass energy alternative using locally produced bioresources is, therefore, required. Gasifier-based systems fill this gap adequately

Previous field experience

Wood gasifiers coupled to diesel engine pumpsets have been disseminated earlier in India on a pilot scale, and have achieved mixed success The characteristics of these gasifiers are listed below

1. Most of these systems were of 3 7 kW rating.
2. They were meant to replace diesel-based pumping systems.

3 This restricted their use to water lifting from shallow wells or streams.
4 Groundwater is the only perennial water source for which they could not be applied.
5 Whenever used, due to limitations of water availability, most pumps were operated under 10% capacity utilization, resulting in poor economics

Alternative options for deployment

The obvious solutions for the deployment of these gasifiers would be to find avenues to:

- extend the facility to small and marginal farmers to enhance hours of use;
- operate on a community/shared basis to reduce overhead and operating costs as well as to increase capacity utilization;
- extend technology for use with submersible pumps;
- operate at a higher installed capacity to serve larger areas;
- depend mainly upon a perennial high value crop which provides frequent cash returns, year-round employment, and woody residues as by-products;
- provide life-saving irrigation to rainfed cereals/oil seed crops during drought periods which is the basis of sustenance (food security);
- develop local management systems which links operation costs to diesel replacement achieved and also permits equitable access; and
- limit overall farm size to match groundwater recharge rates to maintain ecological sustainability.

With these as guidelines, a biomass-based (agro-residue) gasifier running a diesel engine-alternator in a dual-fuel mode was set up to meet irrigation requirements in the vicinity of Pallerayanahalli and Ungra villages in Kunigal Taluk of Tumkur District, Southern Karnataka.

Assumptions

While field experience shows that the following assumptions made at the start of the project are correct, it may be difficult to generalize these for all semi-arid regions.

1 Higher farm returns will arise by a mix of cash and cereal crops.
2 This will pave the way for a higher involvement of technology, resource management skills, and concomitant enhancement in purchasing power and development.
3 Labour and resource limitations, education, and exposure to realistic costs of irrigation (w r t water harvest, related infrastructure, and sustainable handling) would restrict complete switch to cash crops and only a part of the land would be devoted to cash crops
4 This, therefore, would act as internal check, preventing over-exploitation of groundwater and other resources leading to poor sustainability.
5 Villagers are interested in development through a switch to intensive agriculture.

Biomass energy options

The sustainability of a village-level, wholly biomass-based energy use has been reported earlier (Ravindranath, Chanakya 1986). The energy required for irrigation in Ungra exhibits peak demand, and wood gasifier systems were considered ideal. The following field demonstration and issues come to the fore.

1. Sustainable use of captive tree plantations for domestic energy utilities through gasifier systems has also been demonstrated in a neighbouring village for over eight years.
2. The demand for power for irrigation is relatively large and cannot be met from captive tree plantations alone. Therefore, biomass suitable as gasifier fuel needs to be generated from agriculture itself (crop residues).
3. Previous field experience indicates that about 0.4 kg wood is required for every cubic metre of water for irrigation pumped in these areas. Additional woody biomass use may increase pressures on scarce biomass resources.
4. Cultivation of cash crops such as mulberry (sericulture), coconut, tapioca, and castor etc., will provide the required biomass as well as higher cash returns to support gasifier-based power applications. In this region, sericulture is reasonably profitable compared to any other dry land legume, cereal, or oilseed crop.
5. As an example, irrigated mulberry yields 10 tonnes (dry)/ha/year of woody stalks, which are pruned to keep the plant height manageable. Only 40% of this is required to support 16 irrigations in this area.
6. This, in turn, raises issues of sustainability related to:

   - relying on cash crops;
   - a greater reliance on groundwater source; and
   - a need to generate and use wood fuel in large quantities.

Use of groundwater

In this part of the peninsula, annual rainfall is about 800 mm, about six per cent of which recharges the groundwater aquifers (Ramaprasad 1989). Sustainable use of this water source thus limits its use to annual recharge levels equivalent of about 40 ha.mm irrigation/ha/year over the entire village. Water balance calculations may be made to show that with appropriate water conservation (30% run-off) and recharge practices, nearly 160 ha.mm could be stored and utilized from underground aquifers. Alternatively, about 20–30% of the village land could be provided with an additional 750–800 mm of irrigation sustainably.

Local management systems

This irrigation system requires the use of individual biomass resources, the community's groundwater, and a shared utility (economies of scale), which, therefore, requires a community level management.

1. In Pura (a neighbouring village), a community-managed, biogas-fuelled domestic water supply and home illumination system is being successfully run for over nine years and is a role model that could be emulated.
2. A gasifier-based system, similar to the one mentioned above, at Hosahalli village, is in operation for nearly eight years, indicating people's acceptance to this technology and management.
3. Shared lift irrigation systems have also been reported as successful in other parts of the country (e g., *Pani Panchayat* in Maharashtra). This utility is directly linked to people's income, and, therefore, greater local management inputs are required to ensure equitable access and prevent exploitation.
4. Two approaches to community management are possible

   - a community-managed system like that in Pura; or
   - an operator-assisted community management system

The performance and success of these modes are described later. Currently, a village committee, the *Grama Vikasa Sabha* (GVS), oversees its management To derive this benefit, each member supplies 100 kg cut mulberry stalks and meets a running cost of Rs 100 in cash for every 200 m^3 irrigation. The GVS maintains a deposit equivalent to the cash cost of five irrigations for each farmer, which form the working capital. Five irrigations are provided to each farmer on a first-come-first-served basis. About three irrigations are required per crop of silkworms, and each farmer can clear all dues before taking up the next cycle of silkworm rearing. There are currently 22 farmers participating with a total landholding of 6 ha.

Equitable access

Most farmers involved with this project raise mulberry (silkworms) as the main crop The farm size is generally limited to 0 2 ha/family, which is the largest size cultivable using only family labour. It, thus, ensures that no single person exploits the benefits. The accounting and collection of dues are transparent; consequently, every participating farmer is aware of the extent of use by each farmer. Availability of contiguous plots of land of all the village farmers is rare. Extensive underground piping has been used (2.2 km) to reach a large number of farmers The extensive use of underground PVC pipes for water distribution ensures low levels of water loss, but adds roughly 20–30% to the project cost.

System capacity

The 20 kW gasifier based irrigation system was set up to meet the following requirements.

1. In the present situation, each farmer would require 16 irrigations a year, when all the possible six silkworm rearing cycles are carried out.
2. The pattern of use analysed for over two years shows that most irrigations are required in a six-month period between November and June
3. At full capacity, working about 16 hours in a day, this gasifier-based irrigation system can meet crises situations where all the farmers would require one irrigation in 10-day cycles.

4. A 16 ha design capacity for one gasifier unit has been arrived at with this logic.
5. Owing to the non-availability of domestic labour or eggs, or due to pest attacks, one or two rearings are skipped in a year. Due to this, it will be safe to extend the design capacity to 20 ha.
6. Thus, under full capacity, one 20 kW gasifier based irrigation system can meet the year-round irrigation requirements of 100 farm families (0.2 ha/standard family).

Technology hardware

The 20 kW ceramic shell based biomass gasifier, developed and designed at the IISc, has been deployed. Producer gas generated in this gasifier is cleaned through a set of filters and is fed to a 25 kVA diesel engine alternator. The power generated is fed to two submersible pumps of 13.5 kW capacity installed in two borewells, providing a total discharge of 60 m^3/hour at the well head. Water is distributed to individual farms through a network of rigid PVC pipes totalling 2.2 km. When other farms require water, flexible extensions from existing piping network are used.

Mode of operations

When a request is made for water, the farmer brings 0.5 kg of cut mulberry stalks for every cubic metre of water to be pumped (depending on his landholding size). The engine is started on diesel mode and gasifier is ignited. Within 5–10 minutes, the operation is switched to the dual-fuel mode. The gasifier, on a long-term average, achieves 70% replacement and instantaneous replacements recording as high as 88% have been achieved. Recently, the operation has been shifted to a different engine and much higher diesel replacement, has been achieved. About 11 hours of operation is required to provide 50 ha.mm of irrigation Through constant technology improvements as well as by improvements in day-to-day operations and management, technical supervision and maintenance requirements have been gradually reduced.

Economics of operation

Installation costs

The installation costs of this set-up are presented in Box 1. It may be seen from the table that such systems are affordable (less then Rs 6000/household at 1993 costs), and it will be possible to raise such funds collectively or on a commercial enterprise basis. Cost reductions can be achieved in installations where:

- borewell discharges are high;
- borewells, piping, power distribution, etc., are optimized; and
- plots to be irrigated are contiguous.

Operation costs

The current running costs (operation, maintenance, and depreciation) of the system are presented in Table 1 Low running costs can be achieved at installations where there is

Box 1

Installation costs of a gasifier-based irrigation system (1993 prices; Rs)

Gasifier sub-system. gasifier + cooler sand filter; particulate filter coolant water tank as miscellaneous (gasifier related)	75000
Engine genset (power generation sub-system): engine-genset, oil and diesel storage monitoring system, panel board and cabling	200000
Borewell pumpset (water lifting) borewells: 2 nos, pumpsets (total 13.5 kW), accessories and installation	12000
Piping (1.8 km) and controls installation and miscellaneous	100000
Housing civil structure and miscellaneous	35000
Total	530000

Table 1

Economics of gasifier-based irrigation

Parameter	Past	Current	Future
Diesel replacement (%)	70	75	80–85
Area covered (ha)	6	10	20 + 40[a]
Loading (kW)	5 4	13	20
Working hours/year	1000	2000	4000
Farms covered	22	40	100
Cash cost (as per m^3)	0.63	0.50[b]	1.62[c]
Costs recovered	Running	OMD	Total
Payback period	—	—	3–3.5 years

[a]20 ha mulberry/coconut + 40 ha life-saving irrigations; [b]cash cost, (diesel, lube oil, maintenance + depreciation for gasifier shells); [c]capital + operation, maintenance, and depreciation (OMD).

- 60–80% capacity utilization,
- proximity to diesel source (retail outlets);
- long operation hours (>4 hours) at a time;
- wood chips (or equivalent biomass), procured at little cost to the installation; and
- farmers' participation in the management, etc.

Based on the above, the management system was altered in phases to achieve low costs of operation. It may be seen from the table that operation costs are affordable and field experience has also shown that more than 90% dues are regularly recovered. Further cost reduction, as projected in Table 1, is possible when.

- operator skill levels are improved to ensure more than 80% diesel replacement constantly;
- maintenance frequency is reduced by ensuring the use of as dry biomass as possible; operating long periods at a time (more than 4 hours at a stretch), which calls for improved day-to-day management; and
- system expansion (capacity utilization), which will reduce operator costs. Currently, in this learning phase, the system is being operated at about 20% installed capacity.

Cost recovery

These kinds of village-level utilities are placed in areas which substitute some form of subsidized irrigation/power systems. Social benefits (rural development) and health benefits accrued are very high especially since these systems could provide clean drinking water Therefore, its economics with respect to cost recovery need not necessarily be an important criteria. However, field data collected during this period has also shown that capital recovery within three to five years is possible, paving the way for various forms of commercial deployment.

Table 1, and the field experience, show that when water tariffs are collected at Rs 1.60/m^3 of water supplied, capital recovery can be effected within three to five years depending upon the extent of capacity utilization. In this part of the country, it is conventional to share a third of the crop produce with anyone who supplies water for irrigation. This cost works out under this existing convention. These calculations have been made to show that such systems are financially viable in a conventional economic sense rather than suggesting it as the only way. In subsequent dissemination attempts in two villages, villagers have agreed to pay for capital recovery so that dissemination of this technology is possible with only a small seed capital

These calculations have been made at roughly 2700 hours of operation in a year (less than 30% capacity utilization) When power generated is utilized for other industrial and commercial activities in the village, increasing capacity utilization, capital recovery periods could become shorter

Benefits to farmers

At this stage, a few details of the benefits to farmers are available However, overall development indicators have not yet been examined. The gasifier-based irrigation system in semi-arid areas comes as a boon by way of paving the way to assured and increased income, year-round employment, food security, risk-bearing capacity, etc. The benefits accrued include these listed below

1. Year round gasifier powered irrigated mulberry provides incomes in the range of Rs 90 000–120 000/ha · year.
2. Life saving irrigations provided to rainfed cereals reduce risks and increase potential to grow better yielding varieties with accruing food security.
3. Life saving irrigations provided to summer crops (usually vegetables) give very high levels of returns and promotes increased risk-bearing at farm level.

4 Every 1 m^3 of irrigated water used in mulberry creates 0.2 person-day of family level employment (0.1 man-day and 0.1 woman-day).
5 Assured irrigation system is available at an investment cost of around Rs 6000/hh.
6 There is no cash investment at the start of the project.
7. There is equitable sharing and local control over village resources.
8 With minor modifications, this system could be extended to provide drinking water and domestic illumination in the villages

Conclusion

This programme was initiated as a field testing unit for the IISc design gasifier. However, very soon, it was found that by careful planning and field-level management, such projects could be successful elsewhere in the country The major elements of the programme that has led to its success are as below.

1. Reliable gasifier design with shell life upwards of 2000 hours Anticipated shell life is 5000 hours
2. Most villages are provided with 25 kVA transformers or multiples thereof A 25 kVA scale, therefore, overcomes low levels of utilization characteristic of 3 7 kW systems, and increases capacity utilization manyfold.
3. An appropriate field-level management package, as used here, ensures equitable access, sustainable operation, socio-economic stability, improvement of skills, and, finally, avenues for development.
4. Linking increased cash returns and food security, through gasifier-based irrigation, increases beneficiary stake in success and greater participation
5. With appropriate checks on possible exploitation, it is possible to evolve rural development programmes on a commercial basis.

References

Ravindranath N H Chanakya H N 1986 Biomass based energy system for a South India village *Biomass* 6 221–233

Ramprasad 1989 *Groundwater potential and use* Proceedings of the National Seminar. Vidyanagar, Bangalore

BIOMASS GASIFIER SYSTEMS FOR COMMUNITY KITCHENS

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Introduction

In India, fuelwood-fired traditional cooking systems are mostly used in community kitchens operating in a large number of places namely, marriage halls, dining halls, clubs, schools with mid-day meal (MDM) schemes, temples, women cooperatives, and hostels. SPRERI had conducted a survey of selected community kitchens operational at the above-mentioned places (Table 1). While these traditional systems are inefficient and have poor process control, the environmental performance of these systems in terms of CO and particulate emissions is far from satisfactory. Coal, liquefied petroleum gas (LPG), and kerosene or diesel-based cooking systems are also common, especially in urban areas. It has been estimated from the data that the energy requirement per meal in the community kitchens varies from 500 kcal to 1500 kcal depending on the type of the system used and the cooking process adopted.

The fuelwood scarcity is severe and the prices of conventional fuels are rising exponentially. This situation calls for serious scientific inputs towards developing a local resource-based efficient cooking system with better environmental acceptability, economic viability, and process controllability. Biomass gasifier technology is ideal for such applications as it offers all the above-mentioned advantages. Some of the distinctive advantages of the gasifier-based cooking systems over the traditional wood-fired systems are given in Table 2

SPRERI has developed two gasifier-based cooking systems suitable for the above-mentioned applications; one of 16 000 kcal/hour capacity and another of 8000 kcal/hour capacity One of the common distinctive features of these systems is that they operate

TABLE 1
Fuel consumption pattern in community kitchens in the Kheda district, Gujarat

Place/types of cooking system	Number of persons taking meals per day	Fuel consumption per day	Annual fuel requirement
Purohit Dining Hall, V V Nagar			
Traditional wood-fired	300	20 kg wood	6 tonnes
LPG fired		1 cylinder of 20 kg	300 cylinders
Nilgiri Girls Hostel, V V Nagar			
Traditional wood fired	100	30 kg wood	10 tonnes
Primary school, Bakrol with MDM scheme			
Traditional wood fired	350	40 kg wood	10 tonnes
Swaminarayan temple, Vadtal			
Traditional wood fired	600	200 kg wood	72 tonnes
LPG fired		4 cylinders	1440 cylinders
Diesel fired		50 litres	18000 litres

TABLE 2
Comparison of the traditional wood fired and gasifier-based cooking systems

Performance characteristics	Traditional wood fired	Gasifier-based system
Cooking time	Takes more time	Flame temperature reaches up to 850 °C, reduces cooking time
Thermal efficiency	8–15%	45–55%
Process controllability	Poor	Better
Environmental acceptability	Poor; emits smoke, soot, and particulates	Better, no emissions of smoke and particulates
Feedstock acceptability	Accepts various types of agricultural and woody residues	Accepts woody residues of specific size depending upon the system's capacity

totally on natural draft without any electrical input. This makes these systems ideal especially for remote places with no electricity and/or having interrupted power supply.

The economics of the gasifier systems has been worked out. The systems, at this stage, are ready for field demonstration so that the related problems can be identified and steps be taken to rectify them

Systems development

The systems development component had mainly three work phases. Under the first phase, preliminary experiments were conducted to study the concept of natural draft gasification of biomass. Under the second phase, based on the data generated, a 16 000 kcal/hour capacity natural draft gasifier-burner system was designed and developed. Its economics

was also estimated. The system has a gasifier constructed out of firebricks and a producer gas burner as the main components. This is a stationary type unit. Under the third phase, a portable 8000 kcal/hour gasifier based cooking stove was designed and developed.

Development of a conceptual model

For studying the concept of natural draft gasification of biomass, preliminary experiments were conducted (Patil 1991). The conceptual model had basically two main components: a 50-litre capacity cylindrical mild steel drum with perforations on the bottom and a producer gas (P gas) burner fitted at the top of the drum. The unit was operated for more than 50 hours using sun-dried *Lantana camara*, cotton stalks, and groundnut shells as feedstock. The diagonal length of the woody residues used was 30–40 mm.

The gas flow rate can be conveniently varied by controlling the draft from the bottom of the gasifier. The flame temperature varied from 800–1000 °C.

Development of the 16 000 kcal/h gasifier-burner system

Based on the preliminary experiments, a 16 000 kcal/hour capacity gasifier-burner system was designed, fabricated, and installed at SPRERI. The system consists of a natural draft-based gasifier and an aspirated-type producer gas burner. Figure 1 shows the schematic diagram of the final version of prototype model.

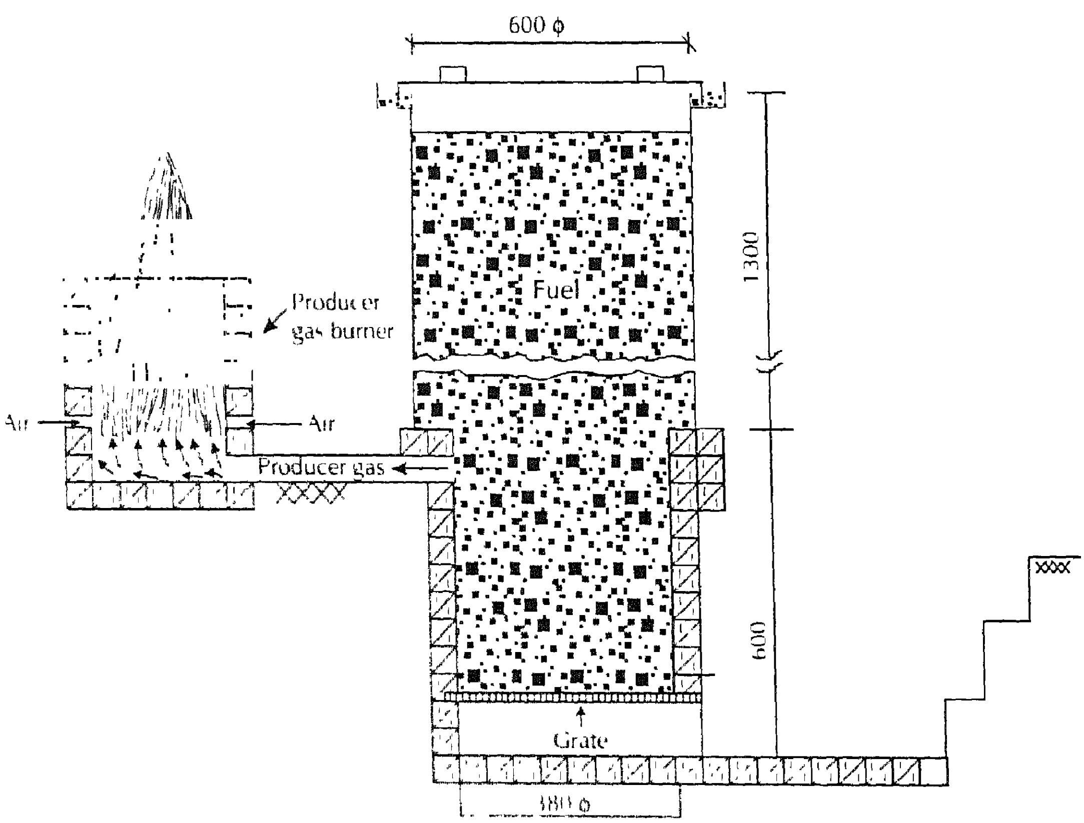


Figure 1. Schematic of a 16 000 kcal/hour capacity natural draft based gasifier burner system for community kitchens (dimensions in mm)

The gasifier is of the natural draft type and has two main components, namely, a reactor made of fire bricks and a hopper made of 3 mm thick mild steel. The P gas burner is of an aspirated type (Priestley 1973). Air turbulators have been provided to achieve a swirling action for the proper mixing of air and P gas.

Development of the 8000 kcal/hour gasifier-based cookstove

The gasifier-based portable cooking stove consists of a cylindrical-shaped gasifier made of 3 mm thick mild steel, a perforated grate of 5 mm thick mild steel, and an aspirated-type P gas burner placed centrally inside the gasifier. The scheme of the system is shown in Figure 2. The provisions have been made to vary the gas production rate and to achieve the proper mixing of P gas and air at the burner.

Performance of the systems

The performance evaluation studies on the gasifier-based cooking systems were conducted using various sun-dried woody residues as feedstocks. Fuel consumption rate, flame temperature, and thermal efficiency were monitored for defining the system performance.

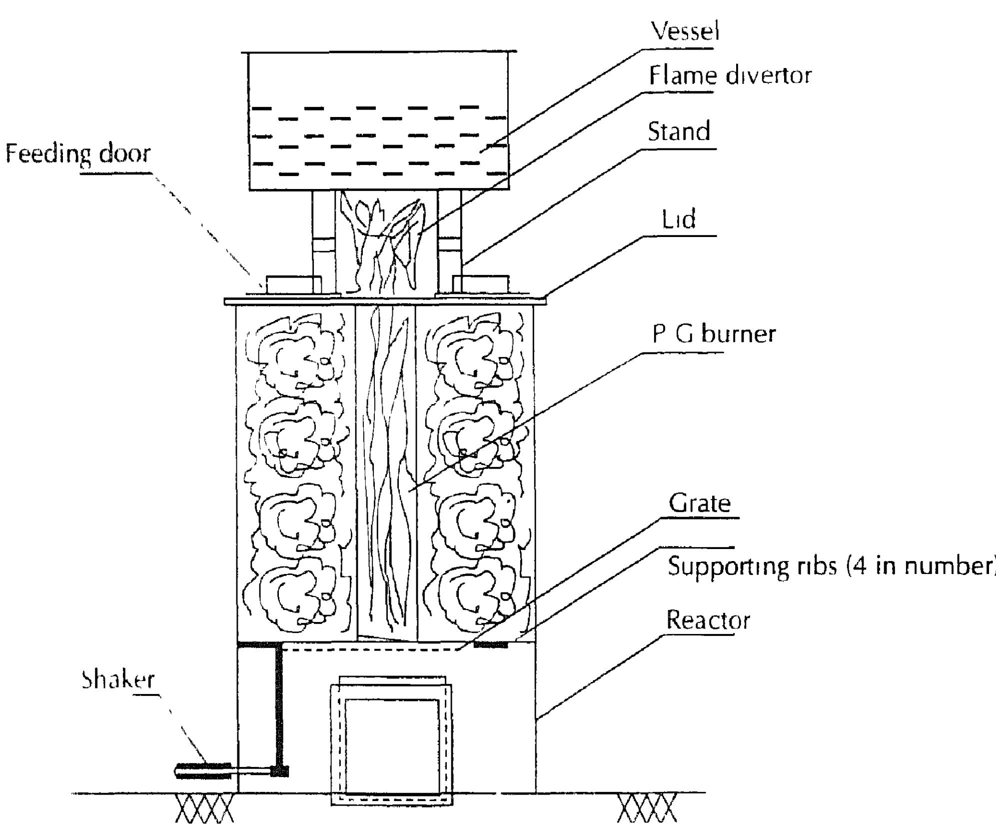


Figure 2. Schematic of a 8000 kcal/hour capacity gasifier-based cookstove

Gasifier system for community kitchens (16 000 kcal/hour)

The gasifier system was operated for a cumulative period of more than 75 hours. Sun-dried *Lantana camara*, sawmill woody wastes, and groundnut shells were used as the feedstock. Chromel–alumel thermocouples were used for measuring temperature and the efficiency was determined by the energy balance technique.

The average values of fuel consumption rate, flame temperature, and the system efficiency were found as 8 kg/hour, 800 °C, and 54% respectively. The system performance was consistent.

The gas flow rate could be conveniently and effectively varied by controlling the draft from the grate. The system could be operated continuously for a maximum test period of 12 hours without any problem.

The system can prepare 275 meals daily if operated for six hours. It has been estimated that if the conventional wood-fired, diesel-fired, and LPG-fired cooking systems are replaced by the proposed producer-gas-based system, the annual benefit to the users will be around Rs 15 000, Rs 29 000, and Rs 18 000, respectively.

Biomass gasifier-based cookstove 8000 kcal/hour

The gasifier cookstove was operated for a cumulative period of 50 hours using sun-dried woody saw mill wastes and *subabul* wood pieces of 20–80 mm diagonal length as feedstock. The flame temperature was found to be in the range of 800 to 950 °C and the average fuel consumption rate was 4 kg/hour The overall performance of the system was satisfactory.

The system in operation was shown to the owner of one of the leading dining halls of Vallabh Vidyanagar The system will be tested at his place to evaluate the performance under field conditions The economic analysis of the model shows that if it is introduced in place of a conventional wood-fired system, the user will have a net annual benefit of around Rs 8000 with a benefit/cost ratio of 1.6. Identification of the market, the assessment of the availability of the specific type of biomass to be used as feedstock, patenting the technologies which usually takes years to obtain, and the large-scale demonstration of the developed gasifier-based cooking systems are some of the important issues in commercializing the developed technologies.

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References

Patil 1991 Simple technology for production of coconut shell charcoal. *RAPA Bulletin*, Rural Energy 1991 1 38–41

Priestley J J 1973 ***Industrial gas heating design and application***. London: Ernest Benn Ltd

RICE HUSK AS FUEL IN SMALL-SCALE CEMENT INDUSTRY

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Introduction

The energy crisis of the 70s brought an awareness all over the world to exploit the non-conventional and renewable fuel sources and conserve the fossil fuels. In countries like India, where agricultural produce is growing significantly [India achieved a record food production of 191.10 million tonnes (mt) in 1995], huge quantities of biomass are generated as waste in the fields and processing industries. These biomass contain various amounts of carbonaceous materials like cellulose, hemicellulose, lignin, pentosan, resin, wax, and oil and are being increasingly used as cheap and assured fuel sources for domestic and industrial purposes The calorific value of the ash-rich biomass is low, while in those rich in oils, resins, and waxes, is high Harnessing of the fuel value of the ash-rich biomass through conventional burning inevitably leads to accumulation of huge amount of ash, and, consequently, creates problem for disposal.

Rice paddy is one of the major foodgrains produced in more than 75 countries in the world India produces about 79 mt of paddy annually. Processing of paddy generates husk, which constitutes about 30% by weight. The husk has no nutritive value and undergoes biodegradation very slowly. However, husk has a calorific value of 3000–4000 kcal/kg and is an important renewable fuel source (Houston 1972; Beagle 1978). Till a few years back, in India, the husk was disposed of either by dumping it in an open heap near the mill site or on the roadside to be burnt. The husk, although it does not burn easily and clearly, is being increasingly used as a fuel for domestic and industrial purposes, replacing coal or furnace oil. Burning rice husk (RH) generates about 15–25% of its weight as ash, consisting mostly of silica (about 90%) and traces of oxides of various metals and non-metals. The

ash being very light, and in a dry state, is easily carried by wind and water, and, in water, it floats. It is difficult to coagulate, and, thus, contributes to air and water pollution. Cumulative generation of ash requires a large space for disposal. Utilization of RH as a renewable fuel source, therefore, calls for evolving a simple way for management of the generated ash.

The silica in RH and its ash is very reactive. Various processes have been developed for preparing different silica-based chemicals like molecular sieve zeolites, sodium silicate, active silica, silicon carbide, silicon nitride, fillers for elastomers, and electronic grade silicon (Houston 1972; Borthakur, Saikia, Dutta 1980; Prasad *et. al.* 1989). Most of these uses are, however, yet to be commercially exploited. Cementitious binders, called RH ash cements, are also prepared based on the pozzolanic property of the ash (Cook, Pama, Damer 1976; Mehta 1979; Chopra 1979; Shresta 1979; James 1986; Cook, Suwamitaya 1981). These binders, essentially mixtures of finely divided ash and slaked lime, do not possess the strength characteristics of ordinary portland cement (OPC) or use in structural works and may be used only for masonry purposes. The strength also retrogresses with time. Reactive amorphous ash, however, has been established as a supplementary cementing material for blending with OPC to obtain high strength, acid-resisting cement (Mehta 1992; Kumar 1993). To utilize RH ash, as a supplementary cementitious material or as a starting material for various silica-based products, it needs to be produced in the reactive amorphous form by burning under controlled temperature conditions, involving specially designed burners or techniques (Prasad *et al.* 1989; Kaupp, Goss 1983; Kapur 1985; Boateng, Skeete 1990). The fuel value of the husk, in most cases of reactive silica preparation, is either lost or could be harnessed only partially. Preparation of reactive silica and its utilization, necessarily involve handling of both the husk and its ash. Handling and transportation of these materials are expensive, dirty, and dusty operations.

Silica is an essential constituent of OPC, the most popular and high demand construction material. It exists mostly as dicalcium silicate (belite) and tricalcium silicate (alite) phases in the cement clinker, made by burning a calcareous and argillaceous raw mix at around 1500 °C. These two phases are responsible for strength and other characteristics of cement, and together account for over 70% of the cement clinker. The tricalcium silicate phase is responsible for the initial strength of cement and require high temperatures for formation (Ludwig, Welter 1980; Dutta, Agarwalla, Iyengar 1967). Cement clinkerization is done either in rotary or shaft kiln. The shaft kiln technology, based on the black meal process is ideally suited for manufacturing cement in small scale to cater to the local need (Dutta, Agarwalla, Iyengar 1967, Dutta, Baruah 1982; Barkakoti, Bordoli, Bandopadhya 1987, Borkakoti *et al* 1993). Large-scale cement manufacturing is done in the rotary kiln.

The manufacture of OPC is a highly energy-consuming process. Depending on the type of process (technology), the requirement of thermal energy for production of cement clinker, ranges from 800 to 1450 kcal/kg of clinker. Under Indian conditions, the mini cement plants following the black meal process consume around 1100 kcal/kg of clinker (Dutta, Agarwalla, Iyengar 1967, Dutta, Baruah 1982; Barkakoti, Bordoli, Bandopadhya 1987, Borkakoti *et al* 1993). The conventional fuel for the black meal process is coke breeze, available from coke oven batteries of steel plants. The rotary kiln technology uses coal, furnace oil, and gas as fuel.

Rice husk was explored as a substitute of the conventional fuels like crude oil, coal in the precalcinator and in kiln rotary cement manufacture (Ahluwalla, Page 1992; Ghosh,

Mohan, Gandhi 1992). Ahluwalla, Page (1992) reported that use of husk in the place of coal, poses certain operational problems, like fluctuations in the temperature of precalcinator, coating formation in calcinator and kiln ducts etc. Ghosh, Mohan, Gandhi (1992) investigated the use of RH as a partial substitute (5–20%) of high ash coal.

Significant improvement in fuel consumption, clinker quality, and cement strength was noted. In spite of these advantages, the scope of continuous large-scale use of RH in the production stream of rotary cement manufacturing is limited due to operational problems, like intergrinding, blending, and homogenization with coal or kiln feed (Ahluwalla, Page 1992, Ghosh, Mohan, Gandhi 1992). Besides, handling and transportation of huge amounts of voluminous husk to the plant site is another limitation. The husk has also been used for small-scale preparation of cementitious binder (Ludwig, Welter 1980) The binders are prepared by burning, in a heap, a mixture containing calcareous materials like lime sludge, lime stone, etc. Burning under such condition leads to loss of heat and is unlikely to raise the temperature sufficiently high to form tricalcium silicate phase as present in OPC.

The Regional Research Laboratory (RRL), Jorhat initiated investigation for developing the technology for small-scale production of Portland cement using RH as fuel and raw material (Misra, Borthakur 1985, 1987; Misra 1989; Barkakati *et al.* 1986; Borthakur, Misra 1989, Misra, Bordoloi, Borthakur 1987; Barkakati *et al* 1992a, 1992b, Barkakati *et al.* 1993, Barkakati, Bordoloi, Borthakur 1994). The stack burnt husk ash may be used as a very good argillaceous raw material for preparing high alite (tricalcium silicate) cement. In the presence of fluxes and mineralizers, clinker containing over 70% alite can be obtained at a relatively low temperature of around 1350 °C (Misra, Borthakur 1985; 1987, Misra 1989). It was also established that carbonized RH, obtained by carbonizing the husk under control conditions and having around 40% ash can be utilized to substitute over 50% of the energy requirement of the black meal process for cement making (Barkakati *et al.* 1986). Further innovation led to development of cement manufactured by the black meal process using RH as a fuel and raw material (Borthakur, Mishra 1989, Mishra, Bordoloi, Borthakur 1987; Barkakati *et al* 1992a, 1992b, Borthakur *et al* 1993; Barkakati, Bordoloi, Borthakur 1994) In the developed processes, in addition to reactive silica, husk also provides fuel for decomposition of the limestone and formation of cement clinker. The generated ash reacts *in situ* with the liberated lime to form cement phases at relatively low temperatures The clinkers are soft and can be ground easily with gypsum to obtain cement of satisfactory technological properties. Some aspects of the process developed and technological properties of the cement produced are highlighted here.

Process

The proximate analyses of an RH sample collected from a local mill, along with those of conventional fuel (coke breeze) and other established fuels are presented in Table 1. The chemical analyses of some limestone and clay samples used for manufacturing cement along with that of the fuel ash are presented in Table 2

The relatively low calorific value of the husk and carbonized RH (CRH) and their high ash and silica content preclude designing raw mix with high lime saturation factor (for

TABLE 1
Proximate analyses of rice husk and other fuels

Fuel	Constituents (%)				Calorific value (kcal/kg)
	Ash	Volatile matter	Moisture	Fixed carbon	
RH	19.50	65.18	8.00	7.32	3215
Carbonized RH (CRH)	39.25	15.08	—	45.67	4000
Coal[a]	5.10	40.18	1.75	52.97	8056
Coke[b]	31.09	8.70	—	60.21	5294

[a] Makum coal field, Assam; [b] Rourkela steel plant.

TABLE 2
Chemical analyses of RH ash, other fuel ash, and some limestone and clay samples

Materials	Constituents (%)								
	LOI	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	K_2O
RH ash	0.46	1.85	88.60	3.54	0.26	0.46	—	2 54	1.82
CRH ash	0.77	7.32	85.10	2.05	0.46	0.77	—	—	—
Coal ash	—	3.14	40.50	7.40	37.05	1.12	—	—	—
Coke ash	—	4.05	54.64	29.65	9.72	1.45	—	—	—
Limestone 1	38.60	46.19	7.77	2.12	1.35	1.82	1.95	0.90	0.05
Limestone 2	38.63	47.20	9.02	2.04	1.74	1.17	—	—	—
Limestone 3	42.00	53.09	0.04	1.13	0.20	1.40	—	—	—
Clay 1	9.30	3.29	53.56	22.18	6.58	0.74	—	0.26	0.15
Clay 2	12.57	1.40	59.15	18.30	7.20	1.18	—	—	—

making high alite cement), unless the limestone is low in silica or additional low ash fuel is used in conjunction with the husk. Raw mix usually contains 65–75% limestone, 4–10% clay and other iron, alumina sources, and the rest as fuel.

The process consists of homogenizing raw mix containing different proportions of pulverized raw materials and pelletizing the same in a disc nodulizer using a spray of water.

The pellets are charged into a conical shaped sintering furnace that has the provision of air entry at the bottom, and are then fired. The temperature of the furnace is gradually increased to desired maximum by increasing the air supply. On completion of combustion, it is cooled to ambient temperature by an air blast. The clinkers produced (30–50 kg/batch) are then interground with gypsum in a laboratory ball mill to Blain's fineness of 3000–3600 cm^2/g.

The burning characteristics of raw meal containing husk are different from the conventional fuel. The burning time for clinkerization of raw mix containing husk as fuel is comparatively short (Mishra, Borthakur 1985). The clinkerization also takes place at a relatively low temperature for the burning time, and the clinkerization temperature for the raw mix containing coal and coke are comparable. In both cases, the samples remain at the

maximum temperature for a longer period before cooling down. When husk is used as a fuel, the temperature rise is faster, and the samples rapidly cool down after attaining the maximum temperature.

Optical and scanning microscopy shows that the clinkers produced using husk as fuel are porous and fused as those of conventional clinkers (Borthakur *et al.* 1993).

Physio-chemical characteristics of clinkers

The free lime, burning temperature (maximum), and phase compositions of some of the clinkers produced using different fuels are presented in Table 3. In the same table, the composition of the fuel used is also shown. The burning temperature of the raw mix containing husk is relatively low. The LSF of clinker 1, produced using husk alone, is accordingly rich in belite (C_2S) phase. This sample even produced at a temperature as low as 1210 °C contains a small amount of alite. The LSF and lite contents in other samples are comparable. The alite content in the sample produced using 80% of the fuel requirement from the husk and at a relatively low temperature (1320 °C) contains the same amount of alite as is produced at 1400 °C, using coke breeze or other fuel.

Technological properties of cement produced using husk as fuel

The physical properties of some cement samples produced using husk as fuel and determined as per Indian Standards are presented in Table 4. The results reveal that cements with wide technological properties can be produced using husk as fuel The cements thus produced, even though are less fine, exhibit early superior strength when compared to the cement containing the same amount of alite and produced using conventional fuel. The hydraulic phases in the husk-burnt clinkers are, therefore, more reactive. The silica generated on the combustion of the husk is very reactive and reacts *in situ* with the liberated

TABLE 3
Fuel composition, burning temperature, and chemical characteristics of some clinkers produced

Characteristics	Samples				
	1	2	3	4	5
Fuel input	100% husk	80% husk	100% coal	100% coke	33% CRH
Burning temperature (°C)	1210	1320	1390	1400	No data
LSF	0 76	0.84	0.84	0.85	0.85
AM	1.95	1 97	1.86	1.76	2.00
SM	2.65	2.02	2.57	2.14	2.30
C_3S (%)	8.42	32.14	30.59	32.74	33.97
C_2S (%)	61.77	42.03	39 31	39.80	39.07
C_3A (%)	10.57	11.28	9.60	11.30	11.72
C_4AF (%)	9.25	9.74	9 07	11.60	9.89
fCaO (%)	3.20	1.21	2.63	2.50	2.75

C = CaO; S = SiO_2; A = AL_2O_3; F = Fe_2O_3; SM = S/(A + F); AM = A/F; LSF = C/(2.8S + 1.2A+).65F); C_3S = 3Ca).SiO_2; C_2S = 2Cao.Si$)_2$; C_3A = 3CaO.Al_2O_3; C_4AF = 4CaO Al_2O_3.Fe_2O_3; and fCaO = free lime.

Table 4

Physical properties of cement samples produced using husk as fuel in comparison to other fuels and the Indian Standards requirement for OPC

Cement samples	Blaine's fineness (cm^2/g)	Setting times (minutes)		Expansion (mm)	Compressive strength (kg/cm^2)		
		Initial	Final		3 days	7 days	28 days
1	3200	75	99	48.0	135	240	360
2	3112	92	117	3.5	330	381	440
3	3557	40	99	2.0	208	300	470
4	3496	47	62	3.0	240	330	450
5	3525	45	98	5.0	330	395	490
Indian standard IS 269	Minimum 2250	Minimum 30	60–600	Less than 10	Minimum 160	Minimum 220	Minimum 350

lime within a short time and the product cools down rapidly The condition favours formation of C_2S in the reactive form. The belite-rich cement, as expected, exhibits low early strength but the 7 and 28 days strength, characteristics are as per the Indian Standards requirement of OPC, except in case of the expansion behaviour.

Conclusion

Production of cement using RH as a raw material and as fuel shows promise as a rural industry in countries like India, where rice milling is the most common agro-industry. On a conservative estimate, 10 tonnes of paddy provides enough husk to produce about eight tonnes of cement. The fuel being freely enjoyable and cheap, the cost of the cement will be low Establishment of small cement manufacturing units adjacent to the demands of the cement, will also bring substantial economic development. Utilization of the husk for such a purpose will eliminate the problems associated with disposal of the husk and its ash, and, thus, help in sustainable growth of the rice mills.

An integrated approach with the involvement of government and private agencies is necessary for the setting up demonstration units for scale-up studies and for the development of appropriate rural technology for manufacturing cement and proliferating the same.

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References

Ahluwalia S C, Page C H 1992. Effect of low grade fuel, combustible wastes and non-traditional raw materials pp 83–122 *In the Proceedings of the 9th International Congress Chemistry of Cement* New Delhi Volume I

Amick J A 1982 Purification of rice hulls as a source of solar grade silicon for solar cells *Journal Electrochemical Society* 12(9) 864–866

Barkakati P, Bordoloi D, Borthakur P C, Borah U C 1986 Carbonized rice husk – a fuel for black meal process for cement manufacture *Transactions of the Indian Ceramic Society.* **48** 2

Barkakati P, Bordoloi D, Bandopadhya S 1987. Raw material characteristics and quality of cement produced following black meal process of cement manufacture *Indian Journal Technology* **25** 129–153

Barkakati P, Bordoloi D, Baruah A C, Borah U C, Borthakur P C. 1992a. A process for making belite rich Portland cement from rice husk complete specifications. Indian Patent File No 993/DEL/92

Barkakati P, Bordoloi D, Baruah A C, Borah U C, Borthakur P C 1992b An improved process for making ordinary Portland cement from rice husk Indian Patent File No 994/DEL/92.

Barkakati P, Bordoloi D, Bandopadhya S, Borah U C 1993 Physicochemical characteristics of cement produced using sulfur bearing fuels in the black meal process of cement manufacture *Cement and Concrete Research* **23** 1185–1194

Barkakati P, Bordoloi D, Borthakur P C 1994 Paddy husk as raw materials and fuel for production of Portland cement *Cement & Concrete Research* **24** 613–620

Beagle E C 1978 *Rice Husk Conversion to Energy* Rome. Food and Agriculture Organization FAO Agricultural Services Bulletin 31 (Chapter 3)

Boating A A, Skeete D A 1990 Incineration of rice hull for use as a cementious material *Cement and Concrete Research* **20** 795–802

Borthakur P C, Saikia P C, Dutta S N 1980 Physicochemical characteristics of silica from paddy husk, its reactivity and probable field of applications *Indian Ceramics* **23** 25

Borthakur P C, Misra K C 1989 Rice husk and its ash promising raw materials for Portland cement *In* the *Proceedings of the National Seminar on Disposal and Utilization of rice husk ash* New Delhi

Borthakur P C, Barkakati P, Bordoloi D, Sarkar S L 1993 Producing black meal clinkers using rice husk as a fuel *World Cement* December 1993, pp 45–49

Cook D J, Pama R P, Damer S A 1976 *Conference Proceeding on Hydraulic Cement Paste* Sheffield University of Sheffield

Cook D J, Suwamitaya P 1981 Rice husk based cement – a state of earth review *Proceedings of the ESCAP/RCTT Workshop on Rice Husk Ash Cement* New Delhi.

Chopra S K 1979 Utilization of rice husk for making cement like binders. *Proceedings of the ESCAP/RCTT Workshop on Rice Husk Ash Cement* New Delhi.

Dutta S N, Agarwalla A K, Iyengar M S. 1967 Manufacture of cement as a small scale industry *POWIET* **10**(3)

Dutta S N, Baruah J N 1982 Production of cement in mini scale using vertical shaft kiln technology. *Cement Industrial* **81**

Ghosh S P, Mohan K, Gandhi R K 1992 Effect of using rice husk and its ash as fuel and raw material component respectively in cement manufacture pp 224–231 *In* the *Proceedings of the 9th International Congress Chem of Cement*, New Delhi Volume 2

Houston D F 1972 Rice hulls in rice St Paul, USA Chemistry and Technology, American Association of Cereal Chemists

James J 1986 Chemistry of silica from rice husk and rice husk ash cement. PhD Thesis. Bangalore· Indian Institute of Science.

Kapur P C 1985. Production of reactive biosilica from the combustion of rice husk in a Tube-in basket burner. *Powder Technology* 44. 63–67

Kaupp A, Goss J R 1983 *Energy in Agriculture* 1 201.

Kumar A. 1993. *Rice Husk Based Cement in Progress in Cement and Concrete*. pp 342–367 Ghosh S N, Sarkar S K, Harsh S (eds) Abi Books Pvt. Ltd

Ludwig U, Welter A 1980 Formation and stability of C_2S and alites. pp. 99–103 *Proceedings of the 7th International Congress Chem Cement*, Paris Volume II

Mehta P K 1979 The chemistry and technology of cements made from rice husk ash, rice husk ash cement *Proceedings of the UNIDO/ESCA/RCTT/PCSIR Joint Workshops.* Held at Peshawar, Pakistan and Bangalore, India.

Mehta P K 1992 Rice husk ash-a unique supplementary cementing material *In* V M Malhotra *Adv in Concrete Technology.* Ottawa CANMET 407 p

Misra K C, Borthakur P C 1985 Alite formation in the rice husk ash – $CaCO_3$ System; Influence of mineralizers in formation *Transactions of Industrial Ceramic Society* 44(5)· 101–105.

Misra K C, Borthakur P C 1987 Alite formation in the rice husk-$CaCO_3$ system pp 40–46 *In* the *Proceedings of the NCB International Seminar on Cement and Allied Buildings Materials* New Delhi Volume 7

Misra K C, Bordoloi D, Borthakur P C. 1987 A process for making Portland cement from rice husk Indian Patent File No 172587.

Misra K C 1989 An investigation on the synthesis of Tricalcium silicate (Alite) cement. PhD Thesis Dibrugarh. Dibrugarh University.

Prasad M R, Velavandhan R B, Abraham P, Natarjan R, Ch. Venugopal. 1989. Extraction of high purity silica from rice husk ash. *Proceedings of the National Seminar on Disposal and Utilization of Rice Husk Ash.* Chandigarh· National Productivity Council.

Shresta R D 1979 Industrial Utilization of agrowaste for making cement like materials pp. 77–87 *Proceedings of the National Seminar on Disposal and Utilization of Rice Husk Ash* Chandigarh National Productivity Council

R & D REQUIREMENTS IN BIOMASS COMBUSTION AND GASIFICATION

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Introduction

Biomass fuels are solid carbonaceous materials derived from living plants and animals which include crops raised specially for energy purposes, wood and its residue, crop wastes such as rice husk, bagasse, municipal waste, and cowdung. The advantages of biomass as a source of energy are listed below

- It is renewable
- The principle of sustainable development can be fulfilled if the rate of consumption is lower than the growth
- It makes a positive contribution to the greenhouse effect and global change, since it operates in a closed system without increasing the total CO_2 content of the atmosphere.
- Biomass fuels contain negligible quantity of sulphur, thus eliminating SO_x emissions and acid rain upon combustion

A vast amount of biomass material is generated in the country through agricultural and agro-industrial operations. The generation of such material is estimated at 370 million tonnes (mt) annually. The break-up of different biomass sources given in Table 1.

On the basis of calorific value, the amount of biomass material generated is roughly equivalent to around 250 mt of coal. After taking into account the present pattern of use of biomass material, it is possible to sustain a power generation of about 17 000 MW

TABLE 1
Break-up of different biomass sources

Biomass sources	Percentage
Wheat straw	33.5
Bagasse	32.0
Rice husk	12.0
Cotton stalks	8.1
Ragi and *bajra* straw	77.0
Coconut and groundnut shells	6.7

through cogeneration, direct combustion, and gasification routes. It is estimated that biomass availability can be increased by 30% if energy plantations are grown on only 10% of wastelands in the country. Presently about 85% of rural energy and 50% of urban energy requirements are met from biomass mostly through the direct combustion route.

India is one of the largest producers of sugar in the world having 421 sugar mills Bagasse is an important by-product of sugar industry and is being used in the sugar mills for the cogeneration of steam and electricity for captive consumption and also for *gur* making. It is estimated that through bagasse, the sugar industry can generate surplus power and supply of about 3500 MW to the national grid after meeting the internal consumption needs. Rice husk is mainly used for generation of steam and electricity, in tobacco curing, and in brick making.

Technologies to convert biomass into energy fall into two broad categories: biological and thermochemical Biological processes involve the enzymatic breakdown of biomass by microorganisms at low temperatures whereas thermochemical processes use high temperatures to convert biomass into energy through direct combustion, pyrolosis, gasification, or liquefaction Since this is a vast subject, thermochemical conversion of combustion and gasification of only plant-based biomass for power generation have been dealt with in this paper

Factors influencing biomass utilization

Several factors pertaining to material, technological, environmental, economic, fiscal, managerial, etc., can influence the utilization of biomass as source of energy, specially for power generation.

Material factors

Biomass materials are highly volatile when compared to coal. Over 80% of the heating value of wood is obtained from its volatile matter. Specific gravity indicates the amount of solid material in a given volume, and is inversely correlated with moisture content. Moisture content depends not only on natural conditions but also the storing conditions – whether stored in ponds or on dry decks. In general, wood from a young tree contains more water than wood from an old tree of the same species. Water contained in the

biomass adds to its transportation cost. An increase in the moisture content from 10 to 30% in straw decreases its calorific value by 28%. The calorific value or heat of combustion for a given volume of biomass material is primarily determined by its chemical composition, moisture content, and specific gravity.

Technological factors

A technology is considered to be successful only after it is commercialized and the operating conditions at the users' end are standardized after solving the teething problems. A lot of work has been done on the thermochemical conversion of biomass materials but it is limited to wood, bagasse, etc. Biomass that can be easily shredded and dispersed in water is good for anaerobic digestion whereas solid woody biomass with low moisture content is more suitable for thermochemical route.

Economic factors

Sometimes the high cost of production could be the main limiting factor in the commercialization of even the proven technologies. In the case of biomass, techniques like densification, briquetting, and gasification could enable the economic use of bulky biomass, but intensive work is required to make the utilization economically attractive.

Fiscal factors

The use of biomass as a source of energy, and the development of conversion technologies and the required equipment is related to the fiscal policies of the government and incentives/subsidies. Such fiscal policies are necessary to substitute fossil fuels with biomass.

Organizational factors

A number of organizations in the country are working on different aspects of biomass utilization. But, keeping in view the multi- and inter-disciplinary nature of the subject, it is beneficial to strengthen and enhance interaction and coordination among the existing agencies rather than creating new ones. Popularization of the biomass utilization programme is equally essential as that of development.

Environmental aspects

The direct combustion of biomass is largely practised for utilization of wood, straw, husk, etc., through *chulhas*, stoves, and boilers. Two major environmental problems are associated through small combustion – deforestation and air pollution. The large-scale combustion compared to smaller ones is known to be environmentally clean. Due to low sulphur content and low combustion temperatures, SO_x and NO_x emissions are not high, and, therefore, do not pose serious environmental problems.

Particulate emissions in combustion are influenced to a great extent by the fuel feed rate, the quantum of fines in the fuel, and the amount of excess air supplied. The size of the particulate in the emissions from biomass-fired boilers range from sub-micron size to 2 mm, and the typical densities are in the range of 30–100 g/m^3. The particulate emissions are controlled to the extent of 99% by staging the combustion and by the use of multi-cyclones, electrostatic precipitators, bag houses, etc.

Two sources of NO_x are formed upon combustion – thermal NO_x and fuel NO_x. Thermal NO_x is formed from the nitrogen in the combustion air at flame temperatures in the range of 1500–1600 °C. Thermal NO_x formation from biomass combustion can be minimized by controlling excess air properly. Fuel NO_x formation is governed by the concentration of nitrogen in the fuel and the method of combustion. Nitrogen is distributed differently in biomass and coal. The NO_x emissions from biomass are significantly lower than coal combustion. NO_x can be controlled by staged combustion. Post-combustion NO_x control techniques are also available.

Fuel gas from the gasification of biomass contains carbon monoxide, hydrogen, and methane, etc., which, upon combustion, becomes harmless since these constituents are converted into CO_2 and water. The fuel gas contains tar which may pose environmental problems and leads to the choking of the gas outlet due to mixing of tar and particulates.

In the storage, transport, and preparation of biomass, there are possibilities for catching fire which have to be properly taken care of.

Technologies for combustion and gasification

Combustion is the dominant and established technology to harness the energy from biomass. Several firing methods have been developed and practised such as grate firing, suspension firing, and fluidized-bed combustion. The selection of the most appropriate firing method depends upon the size of the unit, fuel conditions (moisture, feed size), and the energy product. The grate-fired systems have been widely used because of their ability to handle fuels with high moisture content (up to 60%), to handle fuels with large particle size; and to perform staged combustion.

Grate-fired systems may have flat or inclined grates. The latter can accept very high moisture content fuels (above 60%) and can operate with low excess air of 25% for combustion. These firing systems emit low levels of particulates and NO_x.

The suspension burners firing system is also a matured technology. However, it requires dry (15% moisture content) and finely-sized fuel less than 2 mm. This system requires 100% excess air for combustion in order to prevent excessive slag formation. Suspension burning results in the higher conversion of fuel nitrogen to NO_x.

Fluidized-bed combustion is a new development in the clean and efficient utilization of biomass materials. There are two types of fluidized-bed combustion – bubbling bed and circulating bed. The combustors can burn wet fuels (moisture content 65%) efficiently With the advent of circulating fluidized-bed combustion, the efficiency of biomass utilization has improved. The practice of staged combustion had enabled the minimization of NO_x emissions.

The typical efficiencies for biomass-fired steam boilers range from 65–82%, depending upon the ultimate analysis and moisture content of the fuel and the combustion conditions, such as the percentage of excess air and stack gas temperature. The typical range for excess air and stack gas temperatures is 25 to 100% and 150 to 200 °C, respectively.

One of the most important developments in the direct combustion of biomass is the dendro thermal programme in the Philippines, which consists of the establishment of

power plants using wood from cultivated fast-growing trees as fuel. The programme is to construct 70 power plants with a total generating capacity of approximately 2000 MW and the establishment of 7000 hectares of tree farms by the year 2000 The specific fuel consumption is estimated at 2.25 kg/kWh and 2 34 kg/kWh at moisture contents of 55% and 45%, respectively.

A team from the Nimbarkar Agricultural Research Institute, Phaltan, Maharashtra, visited eight power plants in California, USA, running on wood and agricultural wastes. The capacities ranged from 10 to 25 MW. Out of the eight plants, five are based on fluidized-bed combustion and the rest use the moving-grate, suspension-burning, and circulating fluidized- bed technologies. The overall efficiency of the plants varied from 18 to 30%. The team found that the fuel handling and processing technology and the combustion technology were very well established. All the plants had excellent pollution control systems to adhere to strict environment regulations. The availability of plants was excellent (290–345 days/year). The capital cost for new plants was $3–3 5 million/MW and the cost of generation 8.5–9 5 cents per unit The team was convinced that power production from biomass combustion can easily be applied in India. Based on the visit, the team carried out a techno-economic feasibility study for setting up a 10 MW electric power plant based on biomass combustion

Briquetting of organic residues

Organic residues are difficult to handle because of their bulkiness and lower heat content. It is necessary to compress them into manageable pieces through briquetting for handling and for efficient energy production. Briquetting is most essential to reduce the transportation cost.

A variety of residues/wastes have been used for the manufacture of fuel briquettes, e.g., woodchips, sawdust, barks, stumps, branches, rice husk, straw, bagasse, groundnut shell, and municipal waste. The moisture content needs to be less than 20% for effective briquetting. Drying is necessary before briquetting if the moisture content is high.

The briquettes are an effective substitute for coal. The briquettes can be used in boilers for steam production or in gasifiers. They do not corrode the boiler/gasifier due to the negligible sulphur content

Biomass gasification

Gasification is the thermochemical conversion of biomass into a gaseous fuel by means of partial oxidation at elevated temperatures and pressures. The most widely applied gasification reactors are the moving-bed and fluidized-bed types. The moving bed reactor with the dimension of 1–10 cm is used for biomass. The moving-bed technology is of three types: counter-current, concurrent, and cross-current reactors depending upon the direction of air injection either concurrent or counter current to the feeding of biomass The temperature of the gas leaving the moving-bed gasifier ranges from 400 to 700 °C, depending on the type of reactor. The counter-current reactor is used for direct heating and the concurrent reactor for power generation. The counter-current reactor is more flexible and can handle biomass materials having ash content of up to 20% and moisture up to 40%, whereas the concurrent reactor can handle up to 6% ash and 30% moisture contents.

The moving-bed reactor is sensitive to channelling, which is caused by bad bunker flow, blocking of bed with fines, and by the formation of cinders. Bad bunker flow is mainly due to tar condensation, swelling of biomass, etc. Lowering the bed height may be a solution. Blockage with fines and formation of cinders can be prevented by sieving out the biomass lines or by increasing the rate of ash removal at the cost of process efficiency. Faster speeds grate rotation could lead to the densification of bed.

The fluidized-bed gasifier is used for biomass materials of the size 1–10 mm and can handle a wide range of materials.

The product gas has a temperature of 800–1000 °C and usually contains small quantities of char and large quantities of ash particles. It has a higher throughput per gasifier than the moving bed gasifier because of different operating conditions. The fluidized bed is more difficult in operation compared to the moving bed.

Regular feeding of biomass and removal of ash are critical parameters for all types of reactors. Formation of slag and cinders can be prevented by a proper distribution of gasifiying agents, steam injection, and controlling the residence time of ash in the reactor. The proper functioning of a reactor is highly dependent on biomass properties: the size, and distribution, and moisture contents. The quantity of inserts and how they are mixed with biomass are also important since they influence the formation of slag or cinder. A small quantity of earth sticking on biomass particles may lead to more slagging than high ash content.

Some tar and/or char are produced in gasification, posing handling and environmental problems which get compounded if the ash content is high. Tar is a sticky liquid with corrosive properties. Tar can be collected by condensation and recycled into the gasifier or used for the production of steam. Its production is high if wet wood is used. Staged gasification is a solution for tar problems.

Gasification is useful for thermal energy purposes as well as for the generation of power About 40% of the gas is made up of combustion constituents such as hydrogen, carbon monoxide, and methane. It is a fuel for combustion in internal combustion engines or gas turbines for power generation. Through the gasification route, it may be possible to obtain higher conversion efficiency, up to two times, compared to the direct combustion of biomass The gas can energize even small capacity pumpsets (5–10 HP) thus saving diesel.

Physical and chemical properties of biomass are the deciding factors for the efficient and consistent operations of the gasifier. Moisture content influences the temperatures in various zones of gasifier. Excess moisture needs large quantities of heat for its evaporation, resulting in drops in temperature in oxidation and reduction zones of gasifier. The drop in temperature not only affects the calorific value of gas but also increases the tar content due to incomplete cracking. Therefore, a moisture content of about 15% is desirable for a trouble-free and economical operation

R & D needs and activities

Combustion

Direct combustion is a complex chemical process influenced by the fuel properties such as chemical composition, calorific value, moisture content, and specific gravity. The basic fundamentals of biomass combustion entail mainly three consecutive stages.

- Evaporation of moisture
- Distillation and burning of volatile matter
- Combustion of fixed carbon

The direct combustion of biomass for heat, steam, and power has been, and is expected to continue to be, the principal technology for the use of biomass energy. Even though the burning of biomass is one of the oldest energy-producing methods, research continues to make significant advancements in the art and science of biomass combustion. Research on biomass combustion has focused on improvements of existing systems with respect to ease of operation, higher efficiency, and lower capital and operating costs, and emission controls and abatement measures.

In the conventional direct combustion techniques, there is a difficulty in handling different biomass feedstocks, specially crop residues. The ash can melt and gets deposited on the interior of boilers, which reduces efficiency and makes frequent cleaning necessary.

In order to ensure complete combustion, excess air in the range of 15–150% over theoretical value is generally supplied. It is estimated that at 50% excess air, about 11% of the heat produced in the combustion of fuel can be lost to stack gases. R & D work is required to establish optimum excess air for various biomass materials for efficient combustion.

Water creates problems in the combustion of green biomass materials. If the moisture content is 50% on the wet basis, 13% of the total energy available in the biomass is required just for the evaporation of water. Also, more air must normally be supplied to facilitate evaporation of water which increases gas volume resulting in particulate carry-over and heat loss through stack gases. Water also increases the cost of transportation. Therefore, densification and drying are done before transportation and combustion. There is a need to optimize the energy consumption in drying and reduce the cost of transportation to improve the overall economics of biomass combustion.

Direct combustion of biomass, specially wood, is a proven technology for power generation. But the efficiency is relatively low. The heat rates of power plants based on different fuels are given in Table 2. The low efficiency of wood-fired plants is due to the high moisture content and the low energy density.

New technologies which can mitigate the problems of conventional direct combustion systems to a great extent are: fluidized-bed combustion and whole-tree burning. The temperature of combustion in fluidized beds can be more easily controlled than that of conventional boilers making it possible to limit alkali and slagging. Fluidized-bed combustors are also flexible in the use of different feed stocks. By using the whole-tree burner system, it may be possible to reduce the cost of generation.

TABLE 2
Heat rates of power plants

Plant	Heat rate (BTU/kWh)
Wood-fired	12500
Coal-fired	10250
Gas-fired combined cycle	8000

A promising thermochemical conversion technology called flash pyrolysis is being developed for the production of biocrude oil. It has half the heating value of that of conventional crude oil and can be used in boilers, diesel engines, and gas turbines for power generation.

Ceramic gas turbines are being developed for power production by the direct combustion of small-size biomass powder (less than 80 microns). The technology seems feasible and attractive from the technical, economic, and environmental viewpoints.

Biomass gasification

Biomass gasification occurs in three steps. A detailed understanding of these steps is essential for the design of biomass gasifiers.

- Pyrolysis producing volatile matter and char
- Secondary reactions of the evolved volatile matter in gas phase
- Char gasification

Biomass used in the gasifier can be divided into two categories: in the first category feedstocks are included which can be directly fed to the gasifier after size reduction such as wood, shrubs, and coconut shells. In the second category, the materials include sawdust, wheat and rice straw, and bagasse, which need to be briquetted. Densification of biomass materials is also required for easy handling and for reduction in the costs of transportation. Developmental work is required in biomass preparation and transportation to reduce the cost.

Feeding of biomass to the hopper and its continuous movement in the gasifier is essential for the successful operation of the gasifier. Efficient disposal of ash is important, and delays may lead to slagging and clinker formation depending upon the ash-melting temperature. Study of solid movement through gasifiers is an important area for research to understand the hopper geometry, solid flow bottlenecks, vibrations in the various parts of gasifier assembly, and ash separation characteristics.

The amount of tar in gas depends upon the volatile matter content in biomass and the temperature in the oxidation zone in the gasifier. Uniformity of temperature in the oxidation zone is important to present incomplete cracking or combustion which would lead to increased tar content in the gas This requires the critical examination of geometry, location and size, and number of tuyers in oxidation zone in the gasifier. Two-stage gasification can produce gas without tar.

The following parameters have the most significant effects on gasification.

- Type of gasifying agent. steam or hydrogen
- Temperature
- Residence time of solids
- Presence of calcium oxide or recycled wood ash as catalyst

A significant conclusion from the study is that steam gasification is much more effective than hydrogasification for wood, even if a methane-rich gas is desired in the end-product.

Increase in the temperature of the gasifier resulted in the increase in carbon conversion and methane concentration, both in hydro and steam gasification Carbon conversion is 30–40% higher with steam. Residence time affects carbon conversion. Wood ash and calcium oxide are effective catalysts in gasification.

Although various types of gasification systems have been explored, there appears to be a lack of steady state data on the effects of various operating parameters including the use of catalysts to improve gasification reactions, product distribution, and yield.

The development of integrated gasification combined cycle (IGCC) power generation technology is underway in many parts of the world – Europe, North America, and South America. Both atmospheric and pressurized air gasification technologies are being promoted. There are problems in gas-cleaning systems and interfacing the gasifier and turbine which are receiving due R & D attention.

Emissions from gasification which include particulates, alkalis, tars, and heavy metals can affect the operation of advanced power systems such as IGCC. One of the high-priority research efforts is to develop hot gas clean-up methods to supply suitable quality gas for IGCC, at the same time retaining the thermal energy of fuel gas which improves the efficiency of conversion.

The Westinghouse Electric Corporation and the Institute of Gas Technology (IGT), USA, have been jointly carrying out R & D by applying the hot gas clean-up system developed by Westinghouse for coal gasification and pressurized fluidized-bed combustion, to IGT's RENUGAS biomass gasification process The objectives of the joint research programme are to demonstrate a hot gas clean-up system that is capable of filtering out fly ash/char particulates and to thermally or catalytically reduce the tars and oils in the product gas. The gasification process utilizes a pressurized fluidized-bed gasifier working on air or oxygen. The hot gas clean-up system is based on a candle filter. The recommendations/conclusions drawn from the experimental trials are listed below.

- The stable operation of a filter system with a biomass gasifier appears practical.
- Tar did not have any detectable effect on filter operation, even without the use of a tar cracker.
- The use of a cyclone ahead of the filter vessel leads to the reduction in mean practical size which may cause the formation of a 'difficult to clean' dustcake on the filter.

Based on the experimental results, long-term trials on process development units have been planned to corroborate the data obtained earlier, and to provide operational and design data for commercial scale hot gas clean-up.

Sydkraft AB of Sweden and the Ahlstrom Corporation of Finland are jointly developing IGCC systems based on pressurized circulating fluidized-bed gasification technology for power generation from biomass. As a part of the development programme, a full-scale demonstration power plant was commissioned at Varnamo, Sweden. The plant size is 18 MW and is based on wood waste and chips. Gasification pressure and temperature are 22 bars and 950–1000 °C, respectively.

Westinghouse Electric Corporation, Minnesota Valley *Alfalfa* producers, Stone and Webster, and Tampella Power Corporation are working together to develop a commercial-scale power system based on IGCC that uses farm-grown biomass fuel (*Alfalfa*) in an environmentally and economically sustainable renewable energy system. The power output from gas turbines and steam turbines is 50 and 29 MW, respectively. The plant will have hot gas particulate removal.

R & D activities are being carried out in Europe and other countries on biomass preparation and electric power generation through the direct combustion and gasification routes. The main emphasis is on combined heat and power plants, two-stage gasification for wood and straw, coffering of biomass and coal in pulverized coal-fired boilers, gasification of coal and biomass, fluidized-bed combustion, circulating fluidized-bed boilers, pressurized turbines, integrated harvesting for separation of fuel fraction and industrial wood fractions, planning and controlling methods for fuel production, the inventory of energy wood resources, and production of wood fuel from harvesting residues.

Cogeneration

Indian sugar industry is practising cogeneration by producing steam and electricity from bagasse-fired boilers in back-pressure turbogenerators. Both steam and power are consumed by sugar mills. The sugar industry can generate surplus power to the extent of 3500 MW It is estimated that the mill-wet bagasse per tonne of cane crushed contains 790 kWh per tonne of bagasse, whereas the energy required per tonne of cane to produce plantation white sugar is 35–40 kWh. Thus, there is a substantial waste of energy which could be used to generate surplus power

The main reason for lower power is that the steam produced is at low pressure and temperature of 22 ata and 300 °C, respectively It is projected that by increasing pressure and temperature of steam from 20 ata and 300 °C, respectively to 100 ata and 535 °C, respectively, power potential can be increased by 92%

The potential for cogeneration in sugar mills can be exploited by any of the following routes

- The back-pressure route
- The condensing route
- The gasification route

Various combinations of back-pressure, extraction, and condensing systems can be developed to achieve techno-economic advantages The gasification route is still at the initial stages of development A consortium, consisting of Thermochemic USA and Esvin India, is working out a model for the purpose of cogeneration through bagasse gasification It is estimated that the bagasse gasification route can offer twice as much power for export compared to the conventional route

According to an estimate, it is possible to release up to 10 MW of power to the grid for sugar plants of capacity 2500 tcd through the selective use of equipment and systems, conservation of energy, upgradation of boiler pressure, and improving efficiencies

Conclusions

Biomass production and conversion has attracted attention from the scientists and technologists only recently. The earlier lack of attention can be mainly due to the following reasons.

- Cheap availability of fossil fuels.
- Biomass is considered to be inconvenient to handle and process.
- Biomass energy sources require flexible management.

The most important factors in promoting biomass research are listed below.

- Increasing prices of fossil fuels
- Foreseeable depletion of fossil fuels, particularly oil.
- Pollution from use of fossil fuels specially greenhouse gases.
- Biomass is renewable.
- Biomass contains negligible sulphur.
- The efficiency of conversion of biomass can be sufficiently enhanced with the application of appropriate and advanced technologies.
- Direct combustion is the dominant technology utilized for harvesting energy from biomass but it is characterized by low efficiencies
- Several firing methods exist for the direct combustion of biomass: grate firing, suspension firing, and fluidized-bed combustion. The selection of the most appropriate firing method depends upon the size of unit, condition of the fuel, and the energy product (steam). The grate-fired systems have been mostly used because of their flexibility. Fluidized bed combustion, because of the technical merits, is emerging as an alternative to grate-fired combustion. Whole-tree burning technology has a promising future.
- The gasification technology of biomass has been successfully tried at pilot plant/demonstration stage. The commercialization depends on simple plant design to minimize the investments.
- The pressurized and the oxygen-blown gasification technologies may not be competitive for small power plants, whereas atmospheric gasification may prove to be competitive.
- Air-blown gasification technology appears to be attractive for combined heat and power plants with gas turbine capacities of at least 20–30 MW in order to be competitive with fluidized-bed combustion.
- The conversion of oil-, coal-, and gas-fired boilers to biomass fuel appears to be feasible technically and economically through retrofitting which will enable the refurbishing of old boilers specially to reduce the pollution.
- Further development and improvement in hot gas clean-up systems would make biomass gasification more attractive for combined-cycle power generation.
- Finally, harvesting, collection, transport, and material processing affect biomass utilization technically and economically. Therefore, R & D in these areas is to be continued together with the conversion technologies.

PRODUCER GAS AS A SUPERIOR COOKING FUEL: RESULTS OF EMISSION AND EFFICIENCY TESTS

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Introduction

Biofuels constitute the major source of cooking energy in rural areas of India and other developing countries. Traditionally, these biomass fuels are burnt inefficiently and emit pollutants which degrade air quality. The high prices of cleaner substitutes such as liquefied petroleum gas (LPG) and their unavailability in many locations make the possibility of a rapid shift away from the use of traditional biomass fuels remote. This has increased the dependence on biomass resources, the heavy use of which has global impacts and serious local health implications. However, the growing scarcity of biomass resources makes it imperative to identify alternative energy conversion approaches. The Government of India has implemented intervention programmes such as improved cookstoves, but a variety of problems have been encountered in construction, operation, and maintenance. Installation problems include venting of flues inside the cooking space, unwillingness of users to make a hole in the roof, and failure of stove builders to adhere to the stipulated dimensions on site. Common operational flaws are related to the inability to correctly use the firebox and flue dampers and leaving the second port unused and uncovered. Maintenance problems include failure to clean the flue periodically and user-made changes in stove dimensions (Pal, Joshi 1989). These defects ultimately decrease thermal efficiency and increase indoor air pollution. In addition, the life of improved cookstoves is typically about one year.

In laboratory conditions, the efficiency of improved cookstoves is about 20%, on average, and does represent some improvement over traditional stoves (FAO 1993). However, field studies suggest that fuel savings in actual operation can often be marginal or even

negative (Pal, Joshi 1989). In addition some of the more efficient stoves were found to have higher emission factors of both CO and total suspended particulates (TSP) (Joshi, Saksena 1989). These are problematic because some products of incomplete combustion [CO, methane (CH_4), total non-methane hydrocarbon (TNMHC), and N_2O] have global warming potentials (Smith *et al.* 1992). Particulates and CO in the smoke also have potential health hazards for women and children, such as conjunctivitis, acute respiratory infections, and upper respiratory irritation. Long-term chronic smoke inhalation can apparently lead to chronic bronchitis and, perhaps, lung cancer (TERI 1995).

Given these constraints, there is clearly a need for the effective utilization of these energy sources through more efficient and environment-friendly energy conversion routes Through the gasification process, biomass can be converted to gaseous fuel which can be used efficiently with less emissions Though there is a distinct feasibility of supplying piped producer gas to rural households through commercial mechanisms, no such attempts have been made so far However, the use of producer gas for other thermal applications like large-scale cooking, bakeries, and tea drying has been initiated in India.

Biomass gasification is the process of incomplete combustion by supplying insufficient quantity of air (about 30% of stoichiometric requirement), which converts solid biomass into producer gas consisting of CO, H_2, and other hydrocarbons

In the present study, producer gas made from wood was tested in small-scale cooking devices. The resulting thermal efficiency and emission parameters were monitored and are compared here to those from other cookstoves and fuels to assist in the assessment of alternative fuel cycles for household cooking

Experimental design

All experiments were conducted in controlled conditions in a simulated rural kitchen at TERI's Gual Pahari Campus. A standard water boiling test (VITA 1985) was used for the efficiency measurements. All together, there were three experiments done with a traditional wood stove and three with the producer gas stove designed by TERI.

Water boiling test

The water boiling test is a simple simulation of the common cooking procedure. The test is divided into two phases high and low The high phase involves the heating of a standard quantity of water from ambient temperature to boiling temperature as rapidly as possible. The low phase follows, in which the power is reduced to the lowest level needed to keep the water simmering for 10 minutes During the low phase, the lid of the vessel is opened for 0 5 cm Parameters such as water temperature, amount of water lost to vaporization, and amount of fuel burnt were recorded

A typical gas sampling configuration includes a sampling probe, filter holder, pump, and a tedlar bag. The probe is placed in the hood (Figure 1), through which a constant airflow was maintained by an electrical blower. Oil-free sampling pumps (SKC universal flow sample pump, SKC West Inc.) were used for sample collection. The flow rate of the sampling pump is adjusted to be around 2 litres/m. The sampling pump was calibrated before and after sampling by a soap bubble technique. 37 mm diameter quartz fibre filters were used

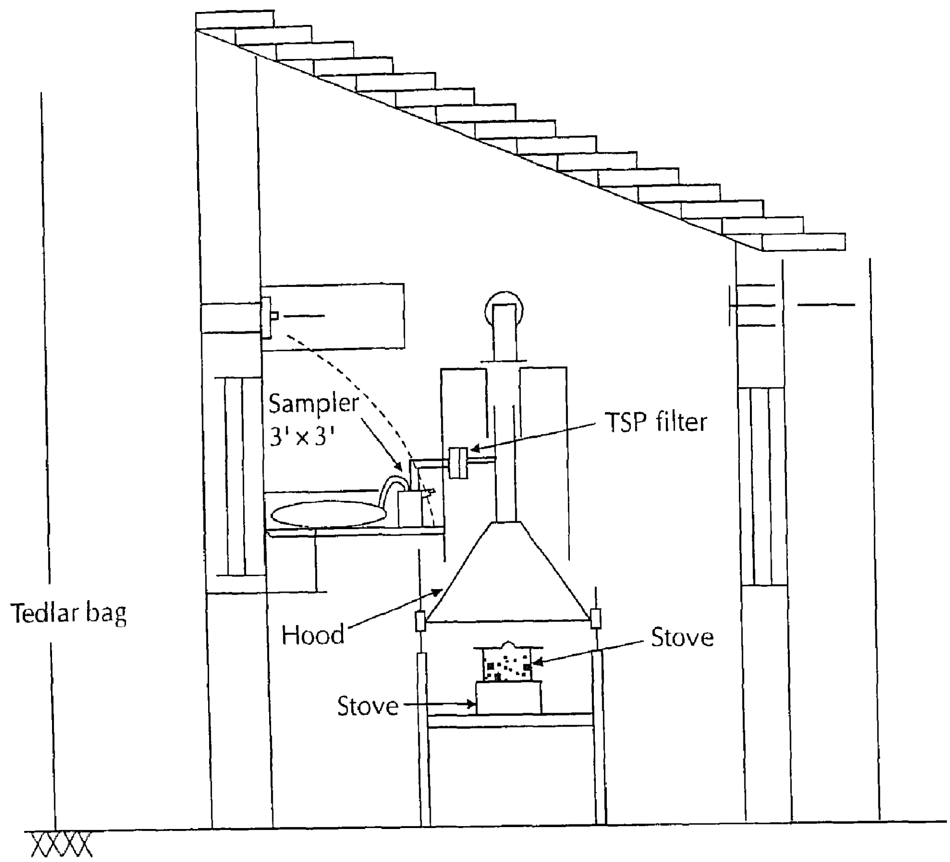


Figure 1. Sampling from stove

to collect TSP Before use, the filters are heated at 800 °C for two hours and then placed into a desiccator for at least 24 hours before being weighed The net weight increase of the desiccated filter after sampling is considered to be the collected TSP. Another probe, pump, and bag were used to collect samples of input air for the stoves.

After sampling, the bags were sealed and shaken well. Glass syringes were used to take the aliquots from the bags. These were injected into a gas chromatograph (GC) for CO, CO_2, CH_4, and TNMHC analysis. A system of GC/flame ionization detector (FID)/ methanizer was employed for analysis of CO, CO_2, and CH_4. In this system, a carbonsphere-packed column was used to separate these three compounds. The CO and CO_2 are converted by the methanizer to CH_4 which is then determined by the FID. TNMHCs are measured indirectly by subtracting CH_4 from the total hydrocarbon, which was using a blank column.

Results and discussion

Thermal parameters such as fuel consumption, burner efficiency, overall thermal efficiency, and duration of the burn-cycle experiment were calculated (Ahuja *et al.* 1987) and are given in Table 1. The mean overall thermal efficiency (31%) is higher than the mean efficiency of wood in traditional stove (15%) and the reported mean (20%) efficiency of

TABLE 1
Comparison of thermal data for producer gas and wood in traditional stoves

Parameter	Wood in traditional stove	Wood in the form of producer gas
Fuel consumption per burn cycle (kg)	0.470–0.540 (0.490)	0.172–0.194[a] (0.180)
Burner efficiency (%)	12–17 (15)	43–46 (44)
Overall efficiency (%)	12–17 (15)	30–32[b] (31)
Power input (kW)	2.96–4.96 (3.95)	1 24–1.28 (1.26)
Duration of burn cycle (minutes)	27–31 (28)	22–25 (23)

[a]@ 2.5 Nm^3 gas/kg wood; [b]assuming a gasification efficiency of 70%.
Note. The values range from minimum to maximum and the value in parentheses is the mean value.

wood in improved stoves (FAO 1993). As shown in Table 1, fuel consumption is commensurately smaller – a 0.18 kg/burn cycle compared to about 0.49 kg/burn cycle in the traditional stove. The duration of the burn-cycle experiment, which is presumably related to cooking time for this type of cooking, is also less in burn cycle experiments with producer gas.

The concentration of pollutants in the flue gas and in indoor background during burn-cycle experiments are given in Table 2 from which the net concentration (flue gas – indoor

TABLE 2
Concentration of pollutants in the flue gas and indoor background during the burn cycle experiment with producer gas

Pollutant	Concentration in the flue gas	Concentration in the indoor background
TSP (mg/m^3)	0.61	0.42
	0 72	0.43
	0.70	0.42
CO_2 (ppm)	2100.00	460.00
	2150.00	380.00
	2490.00	420.00
CO (ppm)	28.00	1.20
	32.20	2.00
	46.00	—
	2.60	—
CH_4 (ppm)	3.40	1.70
	3.80	1.20
	4 00	1.40
TNMHC (ppm)	4.70	2.00
	5.60	1.80
	5.40	2.20

gas) of pollutants was calculated and listed in Table 3. The net TSP concentration for experiments with producer gas (0.25 mg/m^3) is an order of magnitude lower than the mean TSP emission (1.3 mg/m^3) from wood in improved stoves (FAO 1993).

The mean net concentrations of CO, CO_2, CH_4, and TNMHC were used to calculate the ratio to CO_2 (dimensionless) and compared with already reported emission ratios for wood, kerosene, and LPG. Figure 2 shows the comparisons of emission ratios for different fuels which indicate that the emission ratios for producer gas are lower than the emission ratios for wood and kerosene, except the CH_4/CO_2 ratio for which kerosene is lower than the producer gas.

TABLE 3
Net concentration of pollutants (flue gas minus indoor)

Pollutant	Net concentration	Average net concentration
TSP (mg/m^3)	0.19	0.25
	0.29	—
	0.28	—
CO_2 (ppm)	1640.00	1826.00
	1770.00	—
	2070.00	—
CO (ppm)	26.80	33.50
	30.20	—
	43.40	—
CH_4 (ppm)	1.70	2.30
	2.60	—
	2.60	—
TNMHC (ppm)	2.70	3.20
	3.80	—
	3.20	—

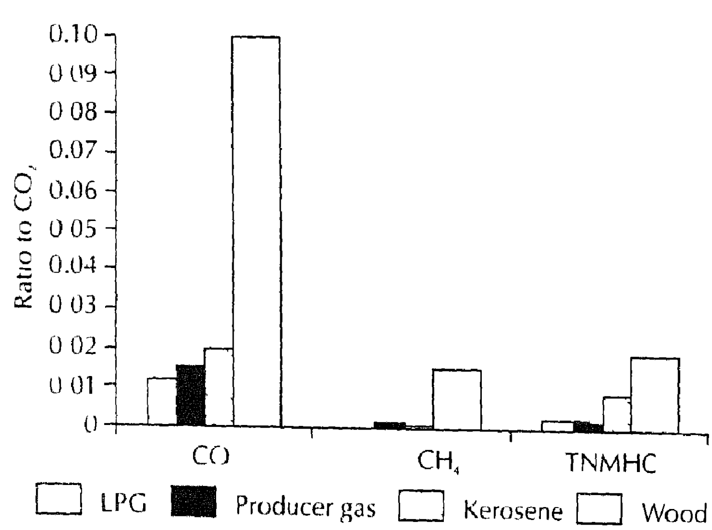


Figure 2. Comparison of emission rates
e. The emission rates for LPG, kerosene, and wood are from Pal, Joshi (1989)

TABLE 4
Emission ratio to CO_2 (dimensionless)

Fuel	CO/CO_2	CH_4/CO_2	$TNMHC/CO_2$
Producer gas	0.018	0.0012	0.0018
LPG[a]	0.012	0.000036	0.0021
Kerosene[a]	0.020	0.00083	0.0088
Wood[a]	0.10	0.015	0.019

[a]from Smith *et al.* (1992).

From the results, it is clear that wood-based producer gas can have higher efficiency and lower emissions than traditional alternatives. The substantially higher efficiencies imply that cooking energy requirements of rural areas can be met from a much smaller quantity of wood/biomass than is currently consumed. A side benefit of this would be that extra biomass thus liberated from cooking can be gainfully used for power generation in rural areas.

As shown in Table 4, the combined effect of higher end-use efficiency and lower emission factors can lead to net emissions per kilogram of food prepared by producer gas that are comparable to those for cleaner fuels such as LPG and kerosene. (This does not, of course, count the emissions during the manufacture of any of these fuels, only at the cookstove.) The impacts on greenhouse gas emissions and rural health could potentially be significant. However, considering that a main constituent of producer gas is potentially dangerous on a short-term basis, substantial R & D efforts related to safety, etc., need to be undertaken before the idea could be commercially exploited.

References

Ahuja D R, Ahuja D R, Joshi V, Smith K R, Venkatraman C. 1987. Thermal performance and emission characteristics of unvented biomass cookstoves. a proposed method for evaluation *Biomass* 12· 247–270

FAO 1993. *Indian improved cookstoves a compendium.* pp 78–81. Bangkok, FAO: Food and Agriculture Organization of the United Nations

Joshi V, Saksena S 1989 Indoor air pollution from energy sources. Paper presented at the Colloquium on Non-point Sources of Pollution; Impact and Mitigation, organized by the Jawaharlal Nehru University, New Delhi. 20 November 1989.

Pal R C, Joshi V. 1989 Improved woodstoves for household energy management – a case study *Productivity* 30(1). 53–59

Smith K R, Rasmussen R A, Manegdeg F, Apte M 1992 Greenhouse gases from small-scale combustion in developing countries A pilot study in Manila EPA/600/R-92-005 (NTIS PB92-139369), pp. 11–13 Washington, DC Environment Protection Agency

TERI 1995. Exposure assessment in slums of Delhi pp 1–3 New Delhi. Tata Energy Research Institute

VITA. 1985 Testing the efficiency of wood-burning cookstoves international standards Arlington, VA: Volunteers in Technical Assistance, Inc.

EXPERIMENTAL OPTIMIZATION OF NOZZLE PARAMETERS LEADING TO DESIGN CONCEPTS FOR BIOMASS GASIFIERS

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Introduction

Kaupp (Kaupp, Goss 1981), based on his extensive literature survey on gasifier designs, calls the design of gasifiers an art rather than science. Nordenswan (1982) surveyed the shapes and design concepts of existing gasifier designs and noted that 'there is no solid, scientifically documented basis for the choice of the most suitable number, diameter, and placement of nozzles. Unfortunately, systematic investigation of these questions has been neglected, and, in the practical design, one has to try to apply, at random, certain findings from experience'. He suggested that the ratio of nozzle area to hearth area and air entry velocity are important design parameters which need to be optimized for each kind of end use. Venselaar (1985) and Graf (1983) have evaluated the optimal nozzle configuration based on the data of large number of successful gasifier designs and presented this data in a convenient form as a function of hearth/throat diameters. It is worth stating over here that, presently, the design rules as outlined by Venselaar (1985) and Graf (1983) form the basis for downdraft designs.

Several other investigators have reported the effect of various nozzle parameters on the performance of gasification process and expressed their concern on the optimization of nozzle parameters (Kaupp, Goss 1981; 1984, Groenveld 1980; Reed, Stassen 1985; Reed, Das 1988; Seng 1984; Reed, Jantzen 1982; Aii 1982; Bhagwat 1986; Parikh *et al.* 1988; Prasad 1988, Sawant 1990). Probably, the notable work on flow properties and flowability [illegible]mass has been reported by Channiwala, Parikh (1992), wherein the particle shape, [illegible] hopper configuration have been optimized for better flowability.

The present work is an extension in the same direction. The effect of nozzle parameters, namely, air entry velocity, nozzle height above the choke-plate, and nozzle orientation has been investigated through simulated cold flow studies, while a more in-depth study has been made on the effect of nozzle orientation on the performance of gasification process through actual performance trials on an experimental research gasifier unit (ERGU).

Experimental investigations

The experimental investigations carried out during the course of this work may be divided in two phases: the cold flow studies (Phase I) and the actual performance trials (Phase II).

Phase I: cold flow studies

To study the effect of nozzle parameters on the flowability of biomass material under cold flow conditions, a special set-up was designed and fabricated This set-up consists of a 300 mm $\phi \times 600$ mm perspex sheet model incorporated with three air nozzles of 20 mm diameter, with a provision for variation of their axial positions and orientation with radial direction, and a calibrated 25 mm orifice meter installed in a 50 mm diameter air inlet line attached to a blower. The blower is capable of providing air velocities up to 20 m/second.

This set-up was utilized to study the effect of air entry velocity, the nozzle height above the choke plate, and the nozzle orientation on the flowability of biomass material in terms of average bed velocities in three distinct stages.

Stage 1: effect of air entry velocity

25 mm quarter cylindrical-shaped particles were selected for this study as they showed better flowability (Channiwala, Parikh 1992). With the nozzle location at 100 mm above the choke plate, with radial air entrance at the 220 mm ring circle diameter, and a choke plate diameter of 130 mm, the flowability of these particles has been measured at different air entry velocities ranging from 0 to 20 m/second.

Stage 2: effect of nozzle height

This study was focussed on the effect of nozzle height on the flowability of biomass material. The flowability of quarter cylindrical-shaped particles, of 25 mm size, through a 130 mm aperture, has been studied as a function of nozzle height, varying from 0 to 200 mm above the choke plate at a constant, radial air entry velocity of 7 m/second at a nozzle ring circle diameter of 220 mm.

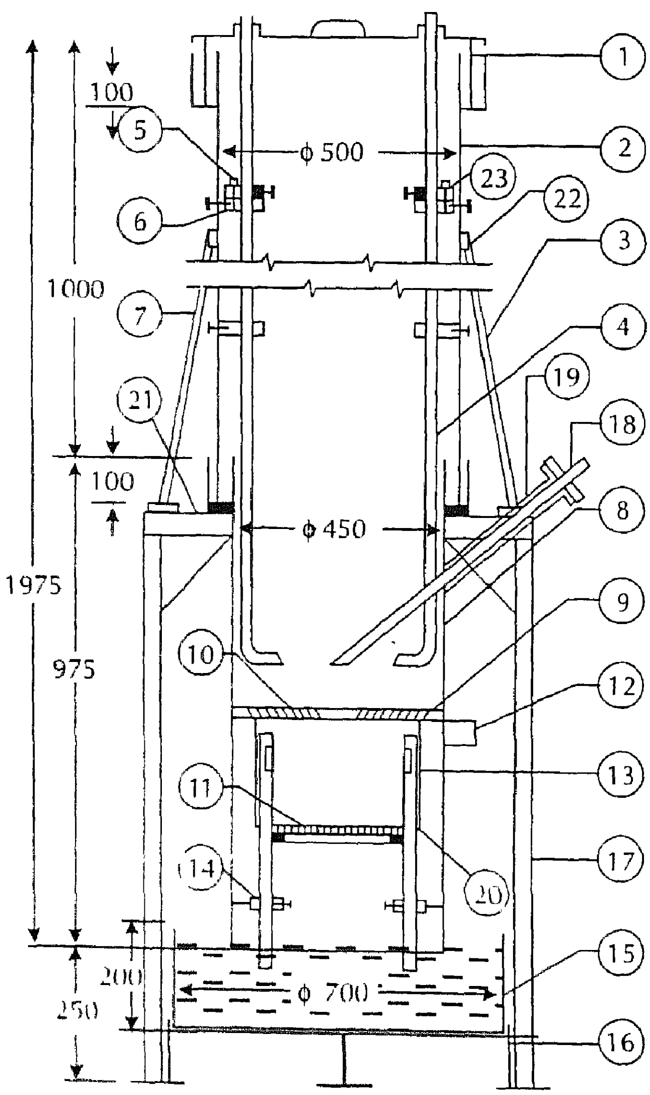
Stage 3: effect of nozzle orientation

Nozzle orientation plays a vital role in the gasifier for producing tar-free gas (Bhagwat 1986; Parikh *et al.* 1988). The extent to which the nozzle orientation effects the flowability of the material has been the objective of this study. The flowability of the quarter cylindrical-shaped particle of 25 mm size through a 130 mm aperture is studied as a function of nozzle orientation varying from 0° to 90° to the radial in a step of 15° at a constant nozzle height of 100 mm above the choke plate and air entry velocity of 7 m/second.

Phase II: actual performance trials

Multi-point air entry with a swirl component helps in reducing the tar content of the gas as observed by Parikh *et. al* (1988). Inspired by these studies, an in-depth study has been made to assess the influence of nozzle orientation on the performance of gasification process through actual performance trials on ERGU (Channiwala 1992). ERGU is a single wall, choke plate type, down draft design, having a gas generation capacity of 45 Nm^3/hour. This unit has a provision to vary almost all design parameters of gasifier including nozzle parameters (Figure 1).

ERGU has been instrumented for several on-line measurements including the axial temperature profile. The temperatures are measured at every 100 mm axial distance, up to a point 450 mm above the choke plate, after which the distance is reduced to 50 mm for obvious reasons. A circumferentially scattered arrangement of 22 gauge chromel-alumel



Part no.	Part name	Material	Quantity
1	LID	MS	1
2	Hopper	MS	1
3	Hopper support	MS	3
4	Air nozzle	GI	3
5	Air nozzle positioner	MS	3
6	Air nozzle support and angle adjuster	MS	3
7	Air nozzle support	MS	3
8	Shell	MS	1
9	Choke plate support	MS	1
10	Choke plate	SS	1
11	Grate	MS	1
12	Gas exit pipe	GI	1
13	Steam pipe	GI	2
14	Steam pipe support	MS	2
15	Water seal tank	MS	1
16	water seal support	MS	1
17	Gasifier support	MS	3
18	Firing nozzle	SS	1
19	Firing nozzle pipe	GI	1
20	Grate support	MS	3
21	Gasifier support plate	MS	3
22	Hopper support piece	MS	3
23	Angle adjuster pin	MS	3

Scale. 1 12 (all dimensions are in mm)

Figure 1. ERGU (rating: 50 kW thermal)

thermocouple assemblies with a variable length of the probes has helped in making such measurements possible at 22 locations along the length of gasifier at an average radial distance of 150 mm from wall

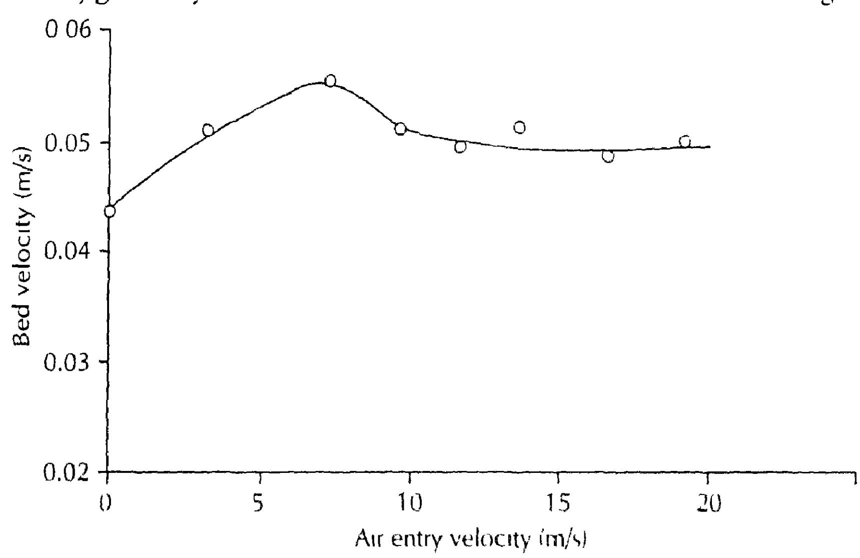
The study on the effect of nozzle orientation on gas quality and performance parameters was planned on ERGU in such a way that the nozzle orientation was changed from radial (0°) to tangential (90°) in steps of 15°. The choke-plate diameter was kept as 130 mm, while nozzle height was set at 100 mm above the choke plate. The reduction zone bed depth was kept as 250 mm. The 40 mm size quarter cylindrical-shaped particles cut from 40 mm diameter *subabul* wood branches were used in this study The gas flow rate was kept constant at 28 + 2 Nm^3/hour and the steady-state observations were taken for a duration of 5 to 6 hours for a given setting of nozzle orientation. The various measured and computed parameters for these trials include gas calorific value, gas composition, tar and particulate content, dry gas yield, wood consumption, exit gas temperature, gasifier pressure drop, equivalence ratio, cold gas efficiency, and axial temperature profile.

Results and discussion

Cold flow studies

Effect of air entry velocities

Figure 2 presents the effect of air entry velocity on the flowability of biomass material in terms of average bed velocities. It can be seen from this figure that as the air entry velocity increases, the flowability of material increases up to an air inlet velocity of 7 m/second, and, thereafter, gradually reduces with further increase in the velocities and gets almost



Particle: 20 mm R x 25 mm (quarter cylinder)

Dc_h = 130 mm, H_N = 100 mm

Figure 2. Effect of air entry velocity on the flowability of biomass material (*subabul* wood)

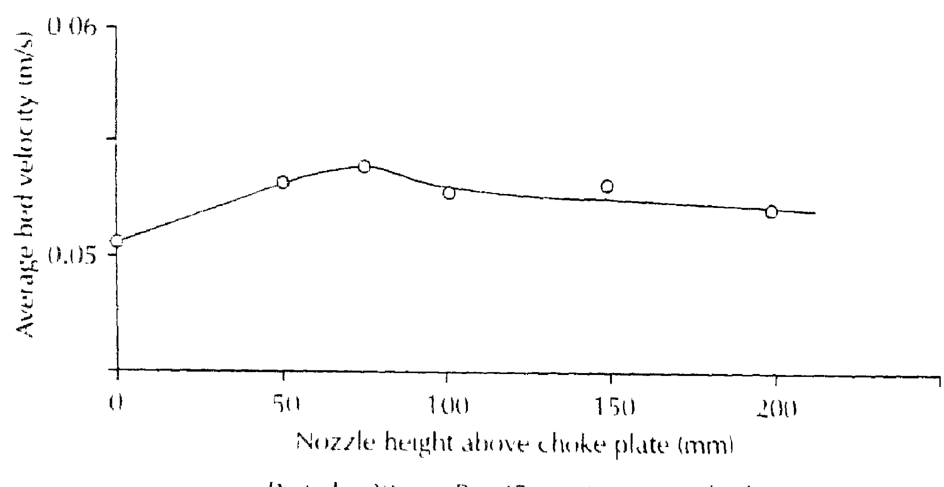
stabilized at the velocities above 12 m/second. Increase in air velocities help in reducing sliding friction at the interface and exerts an air drag on the particles, which results in an improvement in the flowability of the material. However, an increase in air velocities also increases the tendency of local fluidization, which opposes the downward flow of material, thereby resulting in the gradual reduction of the flowability of the material with increase in air velocities above 7 m/second. At velocities higher than 12 m/second, the increased air drag and local fluidization balances each other, thereby resulting in flow stabilization (Brown, Richards 1970; Resnik *et al.* 1966; Cherimisinoff 1986; Shamlou 1988). Groenveld (1980) has also reported the insensitivity of flowability at higher velocities.

Effect of nozzle height

The flowability of biomass as influenced by nozzle height is represented in Figure 3. It is observed that the nozzle height has only a marginal effect on the flowability of the material. There is a little improvement in the flowability of the material as nozzle height increases up to 75 mm (best being in the range of 50–100 mm); a further increase in nozzle height results in gradual reduction and finally stabilization of flow. This may be due to the fact that up to 75 mm nozzle height, air drag does have some beneficial effect and, thereafter, further increase in nozzle height is likely to enhance the bed compactness near the aperture, and, thus, tend to reduce and stabilize the flow of material (Groenveld 1980; Brown, Richards 1970; Resnik *et al.* 1966, Cherimisinoff 1986; Shamlou 1988). These observations lead to the conclusion that the nozzle height in the range of 50–100 mm may be recommended for better flowability of the material.

Effect of nozzle orientation

Figure 4 shows the effect of nozzle orientation on average bed velocities. The figure indicates almost no significant influence of nozzle orientation on bed velocities This can be explained from the fact that under the investigated condition, the radial component of the velocity is the one which will influence the bed flow as discussed earlier. This means that



Particle: 20 mm R x 25 mm (quarter cylinder)

Dc_{o} = 130 mm, V_{a} = 7.0 m/s

Figure 3. Effect of nozzle height on flowability of biomass material (*subabul* wood)

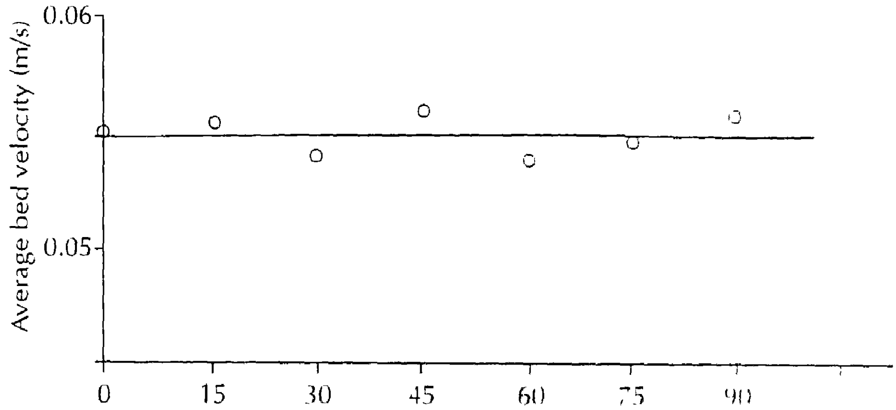


Figure 4. Effect of nozzle orientation on flowability of biomass material (*subabul* wood)

with a constant air entry velocity of 7 m/second, the actual range of radial velocity will always be less than 7 m/second. This should, in fact, have given some increase in bed velocities The magnitude, however, being very small, could not be detected with the present experimental techniques It must also be mentioned here that although the radial component will vary from 0 to 7 m/second, its influence is unlikely to be anywhere near the similar variation of the radial velocity due to several other factors such as particle fluidization, energy loss due to air jet impingement, multi-directional air diffusion, etc (Brown, Richards 1970; Resnik, Heled, Klein, Palm 1966; Shamlou 1988)

These results, although not directly applicable in the design process, do definitely indicate the possibility of increasing the air inlet velocities along with changed orientation of the nozzle, without encountering the ill-effect of high air entry velocities discussed earlier High air entry velocities provided in this fashion have been found to be extremely useful in ash disengagements and control of char quantity entering the reduction zone and, therefore, choking and packing of reduction zone in actual gasifier operation (Kaupp, Goss 1981, Bhagwat 1986, Parikh *et al* 1988)

Actual performance trials

The effect of nozzle orientation on gasifier performance parameters and gas quality have been depicted in Figures 5 and 6 respectively It is clearly visualized from these results that the optimal performance is observed with the nozzle orientation angle in the range of 45 to 60° with radial, while the minimal tar levels are obtained with the nozzle orientation angle in the range of 45° to 75° This typical behaviour can be explained with reference to equivalence ratio, swirl component, and biomass flowability It is observed that when nozzle orientation is changed from 0° to 30°, there is only a marginal change in equivalence ratio and temperature levels of the gasifier, with a further increase in nozzle orientation, the swirl component becomes dominant, and homogenization of the oxidation zone takes place eliminating any dark zones (Kaup, Goss 1984, Bhagwat 1986, Parikh *et al* 1988, Prasad 1988, Sawant 1990) Temperature uniformity of the oxidation zone promotes cracking and burning of tarry products, giving low tar levels of the order of 25 to 50 mg Nm⁻³

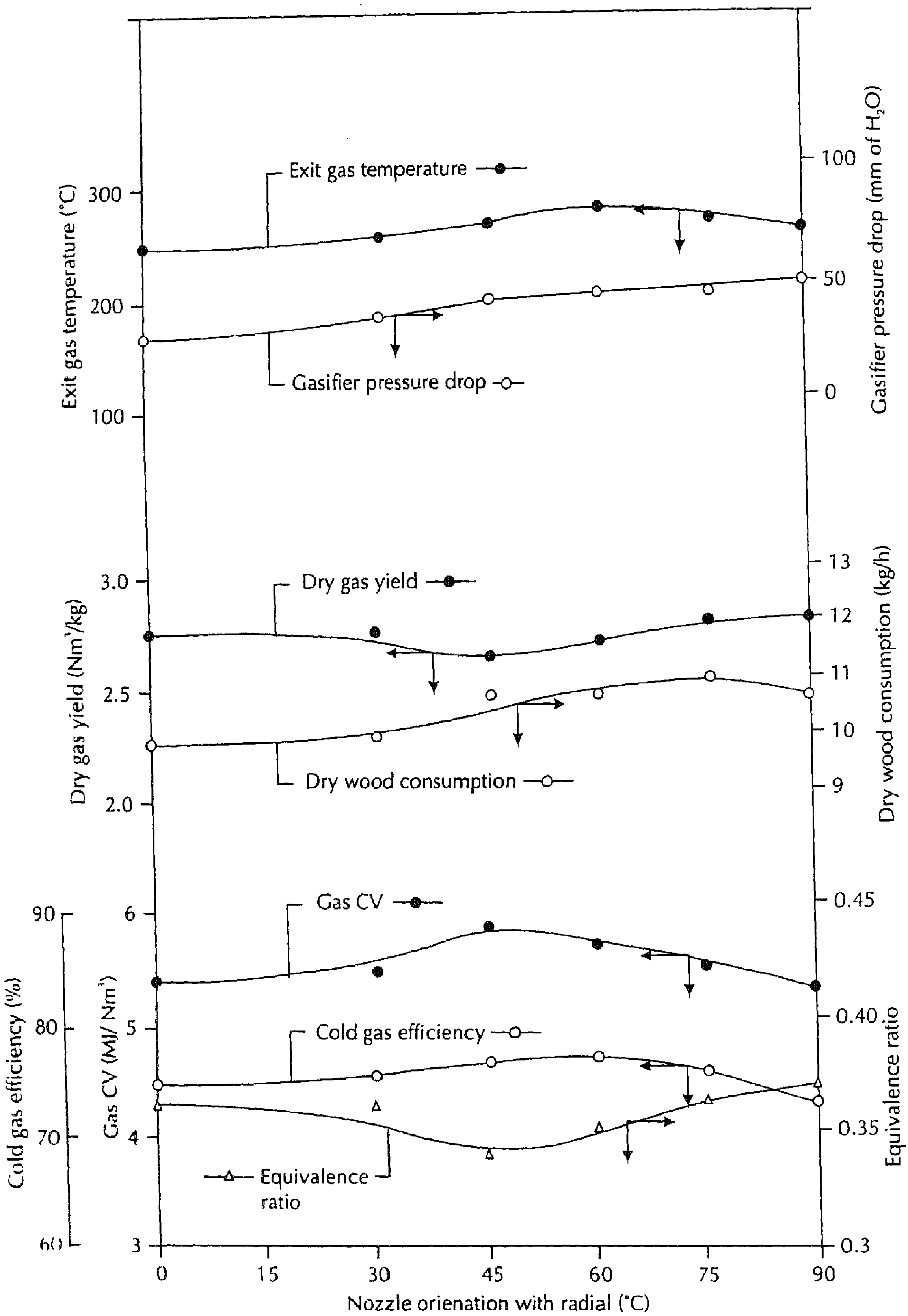


Figure 5. Effect of nozzle orientation on performance parameters of a gasifier (unit: ERGU; particle size: 20 mm R × 40 mm, quarter cylinder)

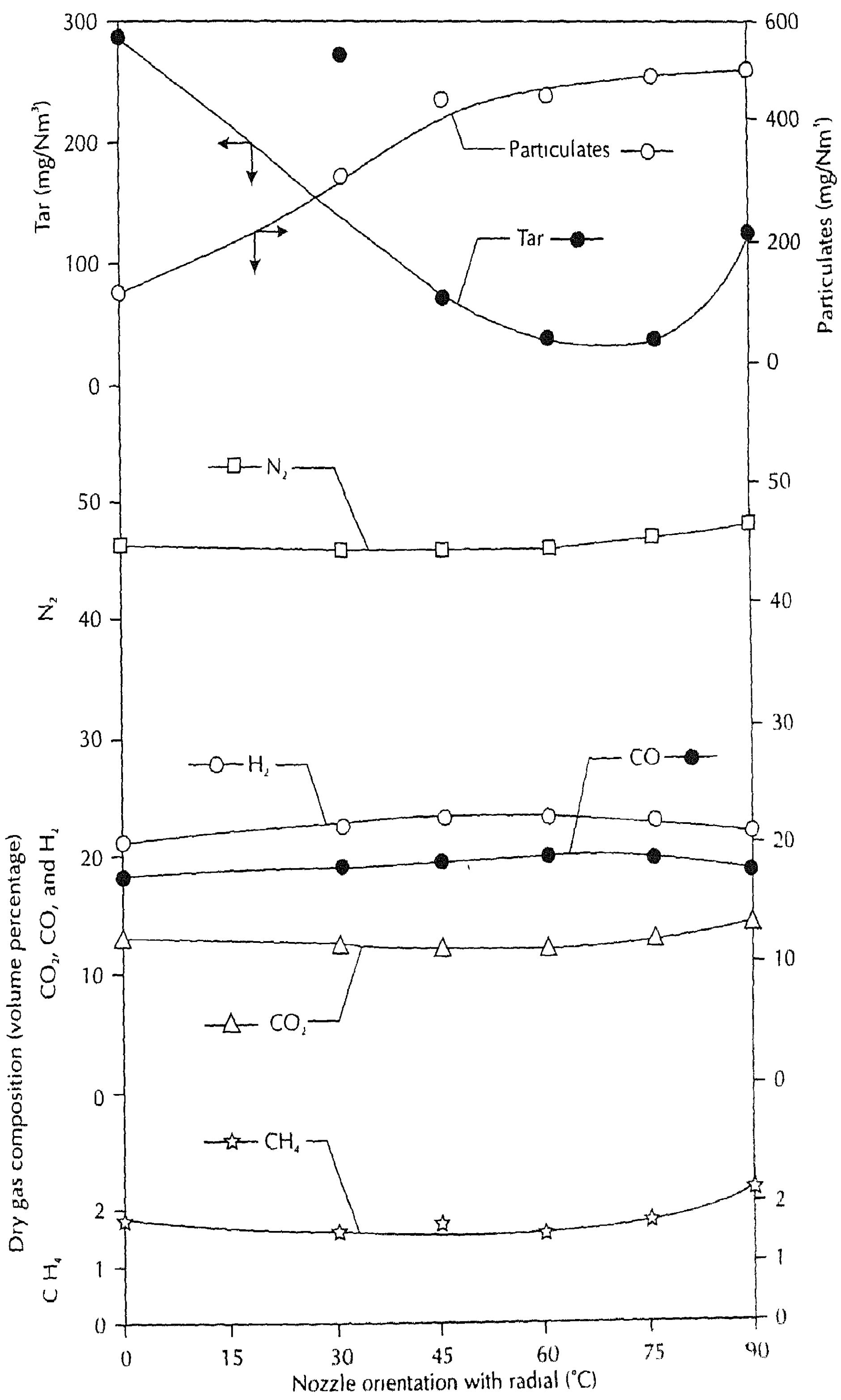


Figure 6. Effect of nozzle orientation on gas quality (unit ERGU; particle size: 20 mm R × 40 mm, quarter cylinder)

in the product gas. The introduction of swirl component also implies increased net gas velocities particularly in the oxidation zone, which, in turn, helps in the easier disengagement of ash off the biomass/char particles. Partial local fluidization of the light char particles is also seen with the introduction of the tangential component, which reduces intra-particle sliding friction and improves biomass flowability as manifested by increased wood consumption. Because of increased flowability, the equivalence ratio reduces and approaches the solid carbon boundary and, thereby, offers better performance in terms of gas calorific value. With further increase in nozzle orientation angle, the effect of the swirl component diminishes, resulting in lower flowability of biomass material and a corresponding increase in equivalence ratio. Reduction in tar level continues up to nozzle orientation of 75°; this time the tar cracking being promoted by higher temperature levels now available due to higher equivalence ratio. At a nozzle orientation of 90° to radial (i.e., tangential), the flame front grazes the gasifier walls, resulting in possibility of creation of central cold spot zones (Kaupp, Goss 1984; Parikh *et al.* 1988; Prasad 1988; Sawant 1990) which may permit uncracked tar to pass along with the gas, and results in increased tar levels at a tangential nozzle orientation. Tangential nozzle orientation becomes objectionable even from the point of view of material life, which, due to a direct contact with the flame front, gets distorted. Also, heat losses from gasifier walls increase because of direct flame impingement on the walls, and, hence, the gasifier performance deteriorates at higher nozzle orientation. The particulate levels increase with increase in nozzle orientation because of higher net gas velocities throughout the bed. Thus, the results of actual performance trials may be summarized as outlined below.

The gasifier produces best gas at 45°, best cold gas efficiency at 60°, and minimum tar levels between nozzle orientation of 45° to 75°. Although, in general, the orientation angle varies from 45° to 75°, the best compromise for all the combinations is obtained at 45° to 60°. This orientation is such that the air entry velocity vector becomes tangential to the plane of rupture of biomass material. This assists not only in the biomass flow, but also in homogenizing the oxidation zone temperature, and, thereby, promotes tar cracking.

Applying simple trigonometry, a design relation for nozzle ring circle diameter, which can be deduced from this observation and from flowability studies, is given by:

$$D_{rr} = \frac{2Hn}{\tan\theta_i} + D_{ch}$$

where D_{nr}, Hn, θ_i, and D_{ch} refer to nozzle ring circle diameter, nozzle height above choke plate, angle of internal friction for biomass material, and choke plate diameter, respectively.

Conclusions

The results of cold flow studies and the actual performance trials carried out on ERGU, with special reference to the influence of nozzle orientation, lead to a few important conclusions.

1. Air entry velocity and the point of entry with reference to the choke plate, influences the flowability. For woody biomass material, air entry velocity in the range of 6 to 8 m/second and nozzle height in the range of 50–100 mm above the choke plate, i.e., 0.4 to 0.8 times the choke plate diameter, improves the flowability.
2. Provision of a tangential velocity component to the air entry velocity vector is beneficial from the point of view of tar minimization. In ERGU, an orientation of 45° to 60° resulted in minimum tar without affecting the performance. This orientation is such that the air entry velocity vector becomes tangential to the plane of rupture of biomass material. This assists not only in the biomass flow but also in homogenizing the oxidation zone temperature, leading to the optimal performance of gasification process with minimal tar levels. This observation offers highly valuable design concepts for nozzle ring circle diameter in terms of various biomass and nozzle parameters as:

$$D_{nr} = \frac{2Hn}{\tan\theta_2} + D_{ch}$$

Acknowledgements

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References

Ati T R. 1982 *Studies of Biomass Gasification* PhD Thesis Berkeley University of California

Brown R L, Richards J C 1970 *Principles of Powder Mechanics* Oxford Pergamon Press

Bhagwat A P 1986 Design, development and testing of a 15 kW biomass gasifier system for engine application MTech dissertation Bombay Mechanical Engineering Department, Indian Institute of Technology

Channiwala S A. 1992 On biomass gasification process and technology development – some analytical and experimental investigation PhD Thesis. Bombay: Indian Institute of Technology

Channiwala S A, Parikh P P. 1992 Flow properties and flowability of biomass. *Proceedings of Third National Technical Meet on Recent Advances in Biomass Gasification Process and Technology*, Vadodara.

Cherimisinoff N P (ed) 1986. *Encyclopedia of Fluid Mechanics* Volume 4 *Solids and Gas Solid Flows* Houston: Gulf publication

Graf U 1983 *Design Rules for Downdraft Gasifiers* GATE Publication

Groenveld M J 1980 *The Co-current Down Draft Gasifier* PhD Thesis The Netherlands Twente University of Technology

Kaupp A, Goss J R 1981 *State of the Art Report for Small Scale (up to 50 kW) Gas Producer – Engine Systems* Davis University of California

Kaupp A, Goss J R 1984. *Small Scale Gas Producer Engine Systems.* GATE Publication. 107pp

Nordenswan G V. 1982 Shape and design of the gas generators. pp. 97–131. *In* Reed T B, Jantzen D (eds) *Gengas – The Swedish Classic on Wood Fuelled Vehicles* Tipi Workshop Book. Colorado.

Prasad S. 1988 *Performance evaluation of a 5 kW wood gasifier system* MTech dissertation. Bombay Mechanical Engineering Department, Indian Institute of Technology

Parikh P P, Bhave A G, Kapse D V, Ketkar B, Bhagwat A P 1988. Design and development of a wood gasifier for IC engine applications – new approach for minimisation of tar. pp. 1071–1087. *In* Bridgwater A V, Kuester J L (eds) *Research in Thermo-Chemical Biomass Conversion.* London: Elsevier.

Reed T B, Stassen H E M 1985 Design consideration for different types of gasifiers *In* Kaupp A, Kjellstrom B, Lacrosse L, Reed T B, Stassen H, Weidez J (eds) *Producer Gas Manual.*

Reed T B, Das A 1988 *Handbook of Biomass Downdraft Gasifier Engine System* Springfield, VA NTIS

Reed T B, Jantzen D (eds). 1982 *Gengas – The Swedish Classic on wood fuelled vehicles* Tipi Workshop Book. Colorado

Resnik W, Heled Y, Klein A, Palm E. 1966. Effect of differential pressure on flow of granular solids through orifices *Industrial and Engineering Chemistry—Fundamentals* 5(3) 392pp.

Seng L H. 1984 *Effect of Design Parameters on the Performance of a Downdraft Wood Gasifier.* ME Thesis. Bangkok, Thailand. Asian Institute of Technology

Sawant S D 1990 *Experimental optimisation of a 5 kW wood gasifier-engine system.* MTech. dissertation Bombay: Mechanical Engineering Department, Indian Institute of Technology

Shamlou P A 1988. *Handling of Bulk Solids – Theory and Practice* London: Butterworths

Venselaar J. 1985 *Design Rules for Downdraft Wood Gasifiers Appendix II* Project JTA-9A Research Development Producer Gas Course, Bandung, Indonesia, March, 1985, Twente University

Section 4

Improved cookstoves

DEVELOPMENT OF MULTIFUEL AND BIOMASS COOKSTOVES

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Introduction

In rural India, about 215 million tonnes (mt) of firewood is required annually to meet the domestic fuel demand at present. However, the forests in India are able to supply only 60 mt of firewood per year due to which the rural people are forced to use sub-standard fuels and wastes such as leaves, twigs, dungcakes, crop residues, coal briquettes, etc. Obviously, all the fuels and wastes are burnt in the traditional stoves, which are very inefficient, resulting in excess fuel consumption and emission of smoke causing health hazards to housewives and children.

Generally, the design of a combustion device or a *chulha* depends upon the physical characteristics, chemical composition, and size of the fuels in order to achieve complete combustion. As a household uses a variety of fuels everyday, it is desirable to burn the fuels in appropriately designed stoves or in a stove having capacity to burn all fuels efficiently. On the other hand, use of a number of stoves everyday is not practicable. Therefore, RRL, Bhubaneswar, has developed a number of multifuel stoves of different burning capacities and construction material for the efficient burning of a variety of fuels as well as wastes in a single device The popular models of multifuel stoves are *Harsha* (family size) (Figure 1), *Harsha* (community size), and *Jyostna* (family size).

The *SK-Delux* multifuel fixed *chulha* developed by RRL is made of steel and clay to reduce the cost of fabrication The unit cost of multifuel stoves ranges from Rs 105 to Rs 150 for the family-size stove and from Rs 550 to Rs 1000 for the community-size stoves. However, many rural households in India cannot afford to purchase the improved stoves at the above cost although these stoves are subsidized and propagated by Ministry of

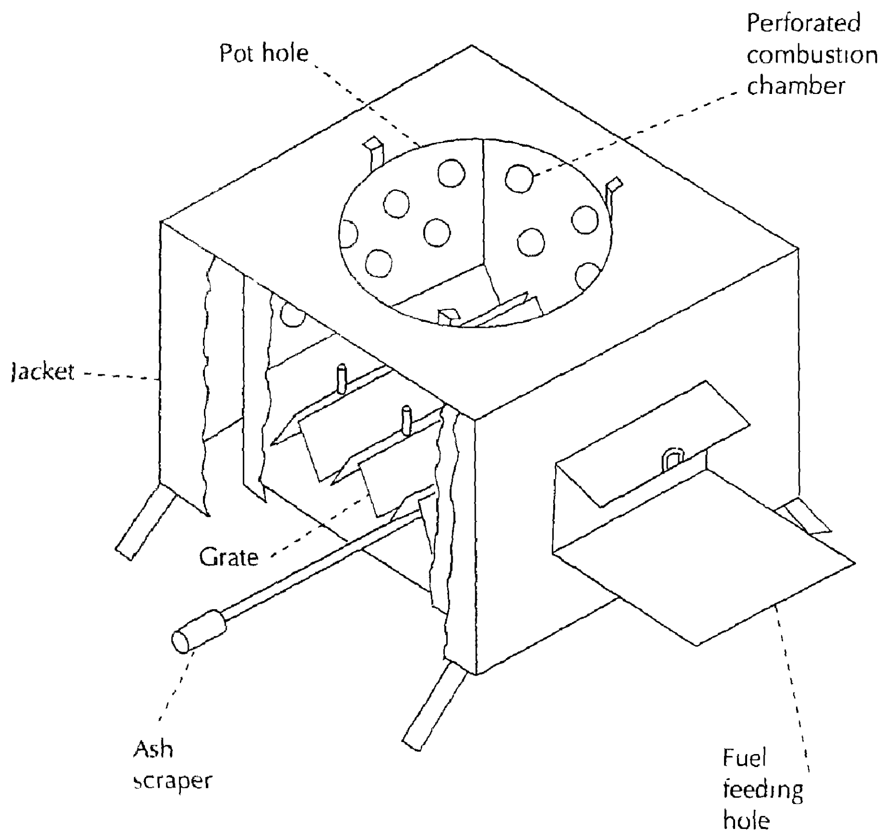


Figure 1. *Harsha* multifuel cookstove (size: 260 × 260 × 200 mm)

Non-conventional Energy Sources (MNES) Also, many households want that their kitchen should be smoke or gas free although the chimneyless stoves emit negligible amount of smoke. In this context, RRL has also developed many fixed *chulhas* without grate for burning dungcakes and agrowastes. These fixed *chulhas* are provided with chimneys, and are constructed with pottery liners cladded with clay. The popular models of fixed *chulhas* are SK-1, SK-2, SK-3, SK-4, etc., having short or long chimneys as per the roof height of the kitchen and suitability of housewives for the maintenance of the *chulhas*. The fixed *chulhas* are also developed for different family sizes. The fixed chulhas cost between Rs 80 and Rs 100. In order to cater to the poorest of the families, a maintenance-free fixed *chulha* called SK-agni, whose material cost is about Rs 35, has been developed. Thus, RRL has developed models to suit the demands of all sections of the people in rural India.

These multifuel and biomass stove designs are good for cooking with different fuels and pot sizes, and for various family sizes, as well as in varying kitchen conditions of rural India However, a number of heating devices besides cooking are also required in the rural domestic sector, and cottage industries such as space-heating, bakery, drying of grains and food materials, etc.

Although some of the rural people use metallic stoves for space heating, an efficient equipment was still needed for cooking cum space heating and other applications. Therefore, the SK-multipurpose Bukhari has been developed to carry out all the various functions together.

This device consists of a multifuel stove connected with a heat exchanger and a chimney. The exhaust gas from the stove passes to the heat exchanger for space heating and various drying and baking processes. After transferring most of the heat energy in the heat exchanger, the exhaust gas goes outside the room through a chimney, so that the vicinity of the device is totally pollution free. This multipurpose stove has a strong market potential for cooking and space heating, as well as for bakery and other heating processes required in various cottage industries in rural, hilly, and cold areas

Presently, the stoves of above designs are available in many states including Orissa, and the *chulhas* are being propagated under the National Programme on Improved *Chulhas* launched by MNES. About 900 000 stoves have already been sold in India in the last three years. Many of the RRL designs modified under different brand names are also being disseminated in the country.

Principle

The multifuel stoves (both portable and fixed models) are capable of burning a variety of fuels containing 1–40% ash and high volatile matters such as firewood, leaves, twigs, dungcakes, agriculture wastes, raw coal, charcoal, etc. All the multifuel stoves consist of a corrugated grate and ash scrapper, perforated combustion chamber, and an air jacket for flow of air in primary and secondary streams The combustion air is preheated through the hot surfaces of the stoves before it is drawn into the stove by natural drafts during burning of the fuels, which occurs in two stages The char or ember burns independently in the troughs of the corrugated grate and the volatile part of the fuel burns completely in the perforated combustion chamber of the stove. The uniform distribution of the primary and secondary air helps complete the combustion of the fuel in the stove. Generally, the ash of the low-ash fuels such as biomass and agriculture wastes, disposes automatically from the grate of the stove due to the optimized inclination of the corrugated plates of the grate, whereas, in the case of cowdung cakes, ash has to be removed from the stove periodically (once an hour) by reciprocating the ash scrapper In the case of coal burning, the ash is not required to be removed during burning as all coal pieces start burning at the same time from all sides of the stove. Due to the typical design of the corrugated grates, the perforated combustion chamber, and the air jacket, complete combustion of the fuel is possible, resulting in a negligible amount of unburnt fuels, and clean burning without smoke Due to the perforation of the combustion chamber, a short flame is achieved whose temperature is always maintained above 800 °C. Fuel combustion has, therefore, been reduced by more than 50% over the traditional stoves

The fixed pottery-lined *chulhas* with chimneys (SK-1, SK-2, SK-3, SK-4, etc) are simple in design and construction These stoves contain a cylindrical vertical pottery liner cladded with clay and a 'U' type tunnel which bridges the chimney with the top part of the stove for

removal of exhaust gases to the atmosphere. The principle of the stove is the complete combustion of the chars or the embers and the volatile matter of the fuels, although the grate and the perforated combustion chamber are absent. Due to the typical dimensions of the cylindrical combustion chamber, the fuel feeding door, and the exhaust tunnels, a stream of air is drawn into the stove, a result of the suction effect of the chimneys, which strikes on the heap of the char or embers at the bottom of the hearth. The embers, therefore, burn continuously and create a high temperature at the bottom of the hearths which helps thermal decomposition and the ignition of the unburnt fuel placed over it. At the same time, another stream of air also enters the stove through the fuel feeding door for burning the volatile matters in a long flame.

Generally, burning of the fuels takes place at the entrance of the fuel feeding door and the flame propagates towards the chimney at the bottom of the cook pot. A higher retention time of the flame is obtained and the flame glides to the bottom of the cook pots which helps a higher rate of the heat transfer from the flame to the pot This saves fuel to the extent of 40 to 50% over the traditional stoves. The SK-multipurpose Bukhari is different from the above-mentioned stoves. It has a multifuel stove whose design is the same as the other multifuel stoves, but the hot exhaust gases of the stove pass through a heat exchanger for various drying, heating, and baking processes before releasing them into the atmosphere through a chimney. The heat exchanger is a downdraft rectangular oven, made out of metallic sheets

Field performance

About 900 000 units (stoves) of the above design have already been disseminated in India during last three years. 300 000 to 400 000 units are being sold annually in India. These figures are based on the reports received from various government agencies, non-governmental organizations, manufacturers, etc. A brief report on the performance of the most popular stoves is given in Tables 1 and 2 and Box 1.

TABLE 1
Multifuel stoves (without chimney)[a]

Model	Materials for construction	Unit cost (Rs)	Thermal efficiency (%)	CO/CO_2	Cooking capacity (person)
Portable *Harsha*	Mild steel (ms)	150	30–43	0.025	8
Jyostna	MS	125	30–42	0 025	8
Harsha (community)	MS	1000	30–51	0 020	50–400
Fixed SK Delux	MS and clay	105	28–40	0.025	8
SK Delux (community)	MS and clay	550	30–42	0.020	50–400

[a] the stoves listed in the table use all solid fuels.

TABLE 2
Biomass stoves (fixed; with chimney)

Models	Materials for construction	Unit cost (Rs)	Fuel	Thermal efficiency (%)	CO/CO_2	Cooking capacity (person)
SK-1	Pottery, clay, and AC pipe	100	Biomass, agrowastes, dung cake	31	0.038	—
SK-3 (family medium large)	Pottery, clay, and AC pipe	80–100	Biomass, agrowastes, dungcake	25	0.035	8–30
SK-3 (short chimney)	Pottery, clay, and AC pipe	50	Biomass, agro-wastes, dungcakes	24	0 045	8
SK-Agni (without chimney)	MS and clay	35	Biomass	29	0 030	8

Box 1
Multipurpose stove (SK-multipurpose Bukhari)

Unit cost of the device	Rs 1200
For cooking and space heating	
Wood burning rate	3.3 kg/hour
Cooking capacity	Up to 15 persons
Heat transfer to pot for cooking	1912 kcal/hour
Net heat transfer to the space (20' × 10' × 12')	8413 kcal/hour
Rise of temperature of the space	19 °C within 2 hours
Thermal efficiency	85%
For space heating alone	
Wood burning rate	3.3 kg/hour
Net heat transfer to the space (20' × 12' × 10')	9721 kcal/hour
Rise of temperature of the space	25 °C within two hours
Thermal efficiency	81%
Typical results of the device when used for bakery	
16–20 breads (1/2 pound each) are baked in a batch within 20–30 minutes	
Wood consumption	2.5 to 3 kg/hour
Quality of bread, bun, cake, etc.	Superior due to uniform temperature
Maximum gas temperature in the oven	450–500 °C

For drying

The temperature of air of a room (20' × 12' × 10') can be raised to 60–70 °C within two to three hours which is sufficient for drying various foodgrains, fish, meat, potato, processing chilly, tobacco, etc., on a cottage scale The device can also be used for drying processes in ceramics, painting, etc.

Advantages

Most of the multifuel and biomass stoves developed by RRL consume 1–1.5 kg of fuel per hour compared to 2–3 kg consumed in the traditional stoves. It has been noted from the users that 40–50% of fuels are being saved by introducing the improved stoves. As pollution is quite low, the health hazard in rural areas caused by the poor burning of the fuels in the kitchen has been reduced significantly. Most of the biomass stoves are fabricated and installed by rural artisans and unemployed youths for whom a good number of employment, over 300 000 mandays per year, has been created in the rural sector. The dissemination of the stoves is being carried out by the nodal agencies of MNES.

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COMMERCIALIZATION OF IMPROVED *CHULHAS* IN MAHARASHTRA

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The Government of India has been implementing a programme called the National Programme on Improved *Chulhas* (NPIC) since 1983 to popularize biomass-based improved cooking devices. Mud stoves, or *chulhas*, form the backbone of this programme. As the cost of the improved *chulha* is subsidized by the government, NPIC is implemented almost exclusively by various government agencies. However, the actual work of constructing and installing the *chulha* in Maharashtra is conducted by contracted workers, who attend a 10-day training course conducted by CASTFORD.

NPIC suffers from a number of practical difficulties. The national annual target of 1.6 million *chulhas* is divided into state-wise targets and communicated to the state-level implementing agency This agency sub-divides this target into district-wise and block-wise targets, so that each block (an area covering about 150–200 villages) gets an annual target of about 500 *chulhas* to be installed in two to three villages.

Usually, the Block Development Officer (BDO) selects the villages, finalizes the lists of beneficiaries, collects the beneficiaries' share of the *chulha* price, arranges to purchase and transport all accessories like the cast-iron grate, the chimney pipe, the chimney cowl, etc., and finds a suitably trained worker to install the requisite number of *chulhas* and pays the worker when the *chulhas* have been installed. The total amount of money involved in this work ranges from Rs 30 000 to Rs 50 000, which is negligible in comparison to funds allotted to other developmental activities like the construction of roads, schools, community centres, drinking water systems, etc. In proportion to the funds allocated to NPIC, the work that has to be put in by the BDO and his staff is disproportionately more, and, therefore, the ease with which the target can be achieved, plays a greater role in NPIC than the actual requirements of the users.

An excellent example of this phenomenon was the fact that in the administrative year 1994/95, nearly 80% of the target in Maharashtra was achieved by just distributing a mass produced portable metallic *chulha* (CPRI Medium Type 1). The surveys later showed that the portable metallic *chulhas* were not being used as the main cooking device in any household, but only as a stand-by device when extra cooking capacity was required.

Another set of problems arises through the system of using a contracted worker called the self-employed worker (SEW). The SEW is an unemployed rural person, who has received training for about 10 days in the art of constructing different models of improved *chulhas.* NPIC does not claim to be a programme aimed at providing cookstoves to the entire rural population of the country, but only as a demonstration for motivating the rural users to accept the concept of fuel-efficient *chulhas*. Therefore, the trained craftsman is contracted to construct only about 300–500 *chulhas* under NPIC. Afterwards, he is expected to conduct this work on his own as a means of earning his livelihood. While working for NPIC, he constructs *chulhas* in the selected households, using the accessories provided by the BDO and the clay prepared by the user. The SEW is supposed to receive a sum of Rs 20 per installed *chulha*, but in actual practice he gets only half of this amount. The remaining half is paid to him in instalments stretched over a period of one year. This mode of payment has been designed to ensure that the *chulha* installed by him lasts for at least a year, but in actual practice it reduces the SEW to play the role of a beggar, paying repeated visits to the office of the BDO. A large majority of the SEWs just give up after a few futile attempts and forgo the dues outstanding to them.

As the earnings of a typical SEW are relatively low, most SEWs quit the work of *chulha* construction as soon as they find a more remunerative alternative. Therefore, the drop-out rate among the SEWs is very high. In spite of several training courses every year, there are still many blocks in Maharashtra without a single active SEW.

Owing to the drawbacks mentioned above, NPIC has failed to achieve the objective of creating a spontaneous demand for improved *chulhas* among the potential users, in spite of almost 12 years of implementation.

Therefore, CASTFORD attempted a different strategy for popularizing improved *chulhas* – commercialization. One of the important criteria for commercializing a product is how it lends itself to mass production. The *chulha* models developed by CASTFORD, namely, *Laxmi* (two pot-holes and chimney), *Bhagyalaxmi* (two pot-holes; no chimney), and *Grihalaxmi* (single pot-hole; no chimney), can all be constructed with the help of a mould. Therefore, they can be mass-produced in a central workshop and transported to the user's house as a ready-to-install *chulha*. This offers a distinct advantage over a mud *chulha* constructed *in situ*, because the latter cannot be used until the clay has dried out, so that the housewife is put to the inconvenience of cooking the meals for almost 15 days on some other makeshift device.

CASTFORD has been conducting SEWs' training courses since 1986. The participants of the courses are selected by the implementing agency, and it was noticed that a majority of the participants did not come from the potter caste. Therefore, the majority of the SEWs perceived *chulha*-making only as a temporary job and not as a profession. The largest number of drop-outs came from this group of SEWs. The potters, on the other hand, make

and sell traditional *chulhas*. Therefore, if after the training period, they are unable to sell improved *chulhas*, they do not quit the work of *chulha* construction altogether because they can still produce and sell the traditional *chulhas*.

Based on these findings, CASTFORD conducted a few training programmes exclusively for persons practising pottery-making as a hereditary profession. The trained potters initially installed *chulhas* in NPIC villages, so that they obtained sufficient confidence in their work. Then, the potters desirous of starting a business based on improved *chulhas* were called to a meeting which was attended by representatives of Maharashtra Energy Development Agency (MEDA), Khadi and Village Industries Commission (KVIC), Khadi and Village Industries Board (KVIB), and some of the financial institutions. These persons explained to the potters about various schemes under which soft loans and other financial assistance could be obtained. During the financial year 1992/93, five potters applied for a loan to start a business based on improved *chulhas*. There were also several potters, who started a business without financial assistance from any source.

In September 1993, a meeting was called to evaluate the success of the commercialization programme. It was attended by 12 potters as also by representatives of MEDA and CASTFORD Prior to this meeting, CASTFORD had conducted a survey of the improved *chulhas* installed by these potters. The *chulhas* were found to be functioning not only to the satisfaction of the surveyors but also to that of the users In the course of this meeting, it was revealed that individual potters had sold from 250 to 600 pieces of improved *chulhas* during the previous year.

The most successful among them had a turnover of about Rs 100 000 during the previous year. The sales figures for the year 1993/94, ranged from 400 to 1000 improved *chulhas* for each potter.

Interviews with these potters, however, revealed that most of them lacked a few basic entrepreneurship qualities. Many of them could not enumerate all the positive aspects of an improved *chulha*, and were, therefore, unable to face a customer who pointed out the negative aspects of these devices. Their success so far was mainly due to personal contacts and the personal services that they offered to the housewife.

A decision was, therefore, taken in the year 1994/95 to conduct entrepreneurship development courses for potters A suitable syllabus was prepared in consultation with some management consultants and a project proposal was submitted to the Ministry of Non-conventional Energy Sources (MNES) for financial assistance in conducting these courses. MNES sanctioned three courses to be held in Maharashtra, and the Government of Goa requested CASTFORD to conduct two courses in Goa. The courses in Maharashtra were held at Pune (for potters in Western Maharashtra), Ambejogai (for potters in Marathwada), and Wardha (to cover Vidarbha) and were attended by a total of about 50 professional potters. The 10-day course included lectures, practicals, and management games covering various topics like market surveys, costing, inventory control, quality control, preparing project proposal for financial institutions, labour management, various schemes of financial assistance to rural artisans, sources of soft loans, tax laws, labour laws, art of salesmanship and advertising, mock encounters with reluctant customers, etc. About 40 participants were already making and selling improved *chulhas* in numbers ranging from 1000 to 2000, before attending the course.

Another attempt at commercialization was made by a tile manufacturer in Ratnagiri district in the Konkan region of Maharashtra. His firm, M/s Shriram Tile Works developed in close collaboration with CASTFORD, a pottery liner set based on the CPRI medium-type portable metal *chulha*. The metal *chulha* is used in the rural areas only as a stand-by cooking device, if extra cooking capacity is required. The pottery liner set, on the other hand, can be fixed in a mud platform, so that it becomes a fixed *chulha*. This set, named *Adhunik Chulha* by the manufacturer, was approved by the Chulha Approval Committee for Maharashtra and Goa. The entire set, consisting of two pottery liner pieces and two cast iron grates, is offered as a kit, nicely packed in a cardboard box, and accompanied by a coloured pamphlet containing instructions about its assembly, use, and care. It is estimated that about 35 000 to 40 000 sets of this kit would be sold during the current financial year.

It has thus been shown that improved *chulhas* can be sold on a commercial basis and that they can generate high income for persons engaged in this profession. The authors are quite confident that this movement would gather momentum, at least in the state of Maharashtra, and would soon grow into a mass movement.

COMMERCIALIZATION OF TECHNOLOGY FOR DOMESTIC COOKING APPLICATIONS

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Introduction

Domestic units are dependent on an inflow of a variety of natural and manmade energy forms to support its existence and survival. Biomass fuels assume a dominant role in the domestic sector to sustain the most energy-consuming task of cooking which accounts for 80–90% of the total energy demand by this sector. The conversion technologies used for cooking by biomass-burning households have remained the same, like the open fire or shielded horseshoe-shaped traditional *chulha* (cookstove) (TC) in most parts, until the entry of intervention programmes initiated by the government to conserve biomass. TCs are inefficiently operated thereby dropping their efficiencies to as low as 2 to 10%. The households, especially women, are unaware of the damage caused to the environment, biomass reserves, and the health and quality of life due to continued use of TCs. Moreover, conventional *chulhas* are counter productive to employment and income generation as well. Energy-intensive cooking practices, spiralling cost of fossil fuels, and fast depleting biomass resources gave an impetus to renewable energy technologies (RETs). The various projections on energy demand have shown that rural domestic cooking continues to be an energy-intensive task drawing heavily on biomass. Further, with increasing demand for solid wood, declining tree resources and low efficient TCs, there would be acute fuelwood scarcity which would lead to diversion of other biomass fuels to the combustion chamber of TCs in rural kitchens. It was observed in a micro-level study that 24% households used dungcakes in 1985 (George 1986) as supplementary or main cooking fuel against 52.9% in 1992 (NCAER 1993). In the context of dwindling biomass energy forms, RETs for cooking have a significant role to play.

National Programme on Improved Chulhas

Among the various RET intervention programmes, the National Programme on Improved *Chulhas* (NPIC) assumes great significance to conserve biomass by virtue of its being the closest alternative option to TCs and its potential for total replacement of conventional *chulhas* in contrast to solar cookers and biogas units. Biomass would continue to play a prominent part in cooking fuel cycles for many years to come in a country like India. India has emerged as a leading nation in efforts to combat biomass scarcity through improved *chulhas* (ICs) In the past decade, *chulhas* have undergone developments and modification due to R & D efforts. From the first generation of ICs in mud with baffle and dampers, the stove technology has evolved to be more appropriate, user-friendly, more efficient, and cost-effective Today, under NPIC, ICs without grating and dampers, ensuring thermal efficiency of above 20%, are implemented. In addition to one and two pot *chulhas* in mud and portable metal *chulhas*, the concept of prefabricated components of the stove has received attention of researchers, policymakers, and implementors since 1988/89. Though the practice of using prefabricated parts was common in the case of TCs in some states like Kerala and some parts of Tamil Nadu, it was a new concept for most of the remaining states of India. The major thrust of NPIC lies in installing a stipulated number of ICs, for example, 2.4 million during 1995/96, fixed or portable metal type, from among the models approved for promotion at an estimated outlay for release of funds in advance at the rate of Rs 100 per *chulha* for the north-eastern region states Jammu and Kashmir, Himachal Pradesh and Sikkim and Rs 65 per *chulha* as per target allotted to all other states, union territories, and implementing agencies. The subsidy from the government is limited to 50% of the unit cost subject to a maximum of Rs 50 in the case of fixed *chulhas* and 33% unit cost subject to a maximum limit of Rs 50 for general category and 50% of unit cost subject to a maximum limit of Rs 75 for scheduled castes (SC)/ scheduled tribe (ST)/hilly areas in the case of portable metal *chulhas*. In contrast to the cost sharing of ICs by beneficiaries, the TCs are zero private cost devices in which zero private cost fuels are burnt. In such a socio-economic and cultural milieu, the IC of the closed type with a flue duct system and chimney itself is a new concept Added to this novelty is that of prefabricated components of IC in pottery.

Major observations on performance of ICs

Functional status of ICs in the field

NPIC is nearly a decade-old programme, with ample feedback monitoring and evaluatory studies which throw light on its functionality rate constraints and facilitators of its acceptability These investigations, undertaken by technical backup units (TBUs) under NPIC in different states, regional offices of the Ministry of Non-conventional Energy Sources (MNES), implementing agencies, and third parties like the National Council of Applied Economic Research (NCAER), and the Operations Research Group (ORG), have been the backbone of the programme to periodically review and revise strategies of implementation. There has been a phenomenal growth in the number of ICs installed – 812 000 at the end of March 1985 to 20 5 million approximately by the end of March 1996. NCAER (1993) on the basis of the evaluation study conducted on 13 000 ICs (installed during

1989–1991) reported that the national average of functional ICs was 61.8% with the averages of those installed during 1988/89, 1989/90, and 1990/91 being 49, 59 5, and 73.4%, respectively, inclusive of those negligible proportion of ICs temporarily not in use. Not much difference existed in the rate of functional *chulhas* used by different castes among the beneficiary households, being 56% and 58% for SC/ST and general category households All-India average for ICs that went out of use within 12 months of installation was 33% and for those surviving beyond 12 months, the figure was 40%. 'The average proportion of working *chulhas* in the case of portable models was computed at 67% against that of 56% for fixed ICs. Similarly, the proportion of working *chulhas* with a prefabricated liner was estimated at 61% as against 51% of ICs made in mud (NCAER 1993). A micro-level assessment of functionality rate of selected models of ICs reveals further the merit of pottery-lined ICs over mud ones both in the case of *chulhas* with and without the flue duct system. The survival rate of ICs with the passage of time and supremacy of pottery-lined ICs over mud ones of the same kind in terms of its functionality rate at the end of nearly one year after installation are self-evident from Figures 1, 2a, and 2b

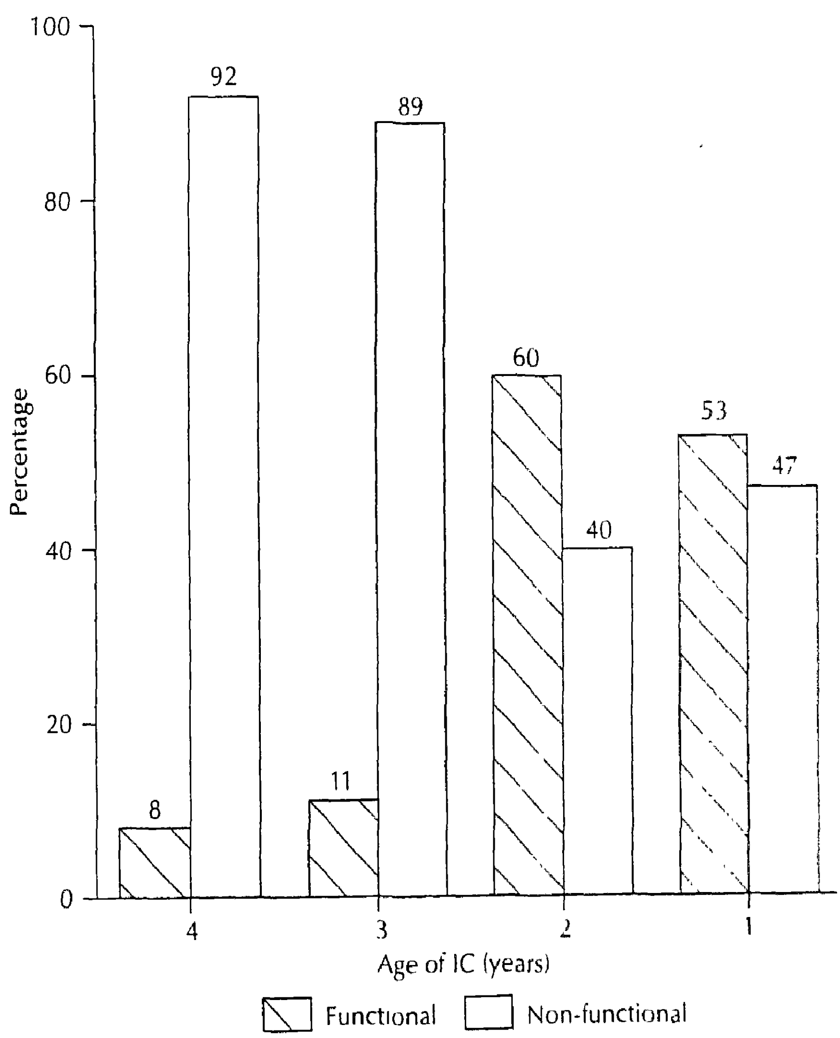


Figure 1. Survival rate of ICs

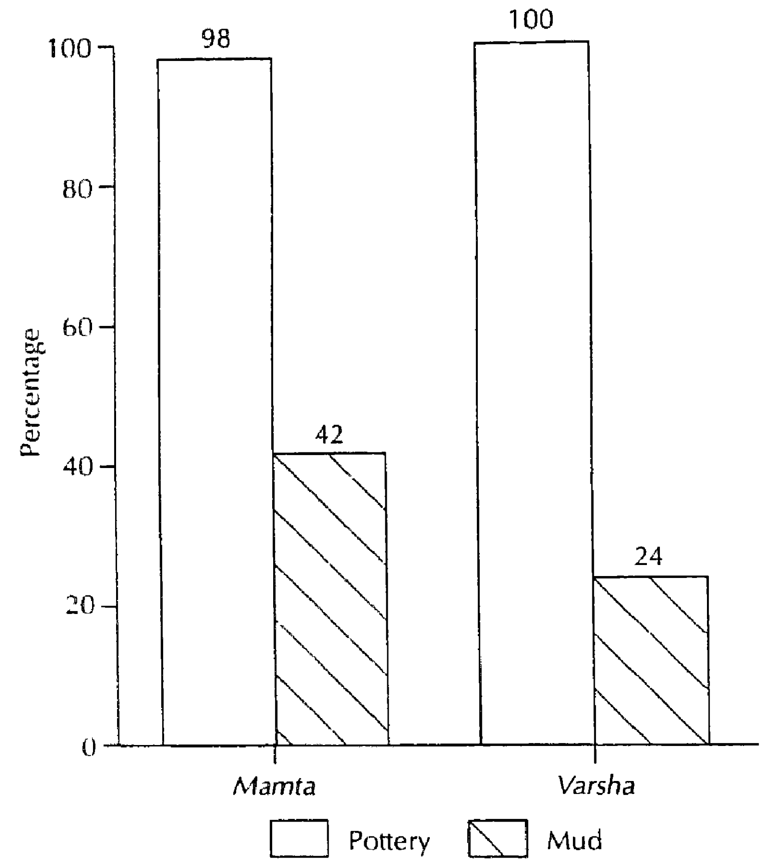


Figure 2a. Functionality rates (%) of selected models of IC

Similarly, Figure 3 explains the performance of ICs in pottery and mud in comparison to the TC as perceived by its users with reference to fuel saving, time saving, and less smoke in cooking In contrast to the 75–60% of ICs in use for one or two years after installation only 8–11% are in use after four and three years of installation (Figure 1) The rate at which ICs go out of use increases with the passage of time, with nearly 90% being abandoned by the end of four years and the beneficiary switching over to TCs Then the goal of biomass conservation in the long run remains far from reality within the existing framework of implementation The contributory factors for non-revival of abandoned ICs, amongst others, were the lack of infrastructure for replacement/reinstallation, increasing the drop-out rate, non-availability of trained self-employed *chulha* workers, lack of skill on the part of its users to remake IC, and poor experience in terms of quality of follow- up and training. Those users who would like to sustain use of ICs are unable to do so in the current context of its implementation (TBSU–NPIC 1995/96). While variables like the perceived cost–benefit ratio (PCBR), energy management practices, extent of participation of beneficiaries (main cooks) and their families in NPIC, and quality of installation of ICs correlated positively with the extent of adoption of ICs, PCBR and quality of installed ICs emerged as the most significant predictors of the extent of adoption of ICs in the presence of other variables (George, Yadla 1995a).

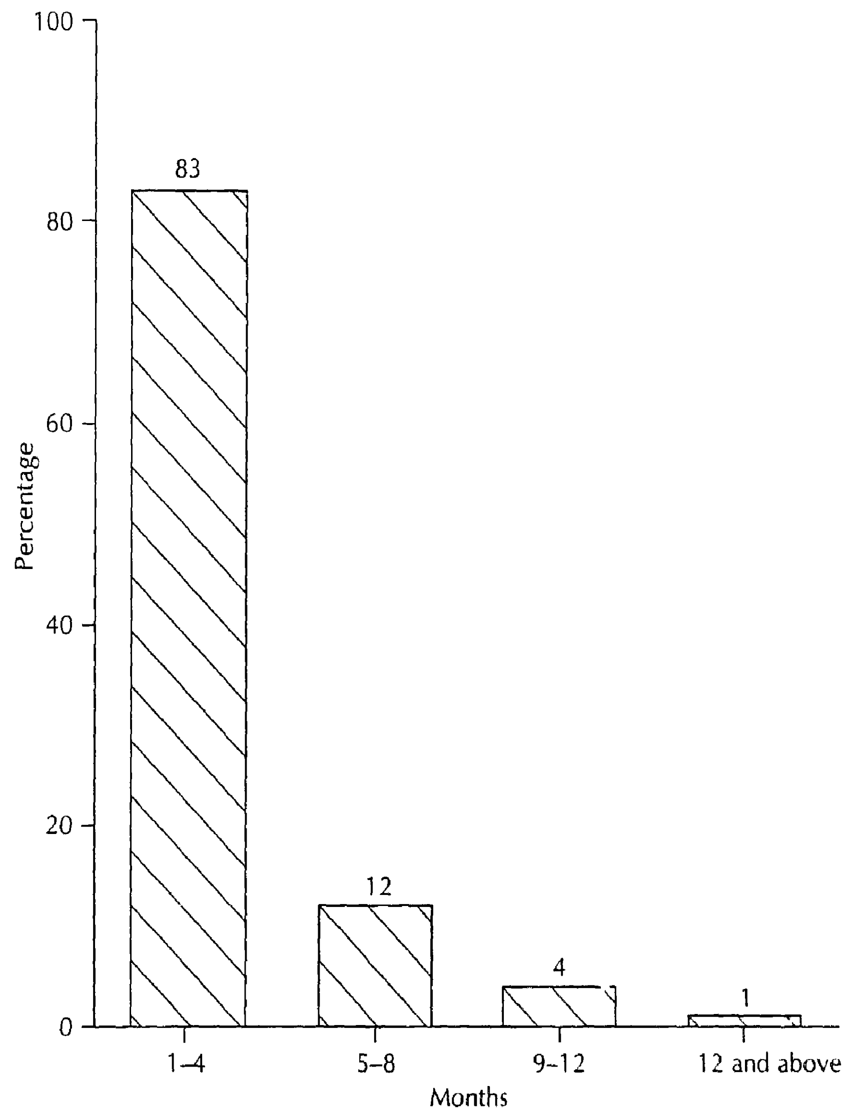


Figure 2b. Duration of use of IC prior to its demolition

Conservation potential of mud/pottery lined ICs and TCs

An attempt has been made by TBU–NPIC, Baroda, to assess the performance characteristics of selected ICs, namely *Kiran* (one-pot) and *Varsha* (two-pot) chimneyless models, *Mamta* (two-pot) model with chimney and TC. These ICs are designed and developed by TBU at the Home Management Department, MS University of Baroda. While the findings obtained from standard water boiling test as per MNES are presented in Table 1, those obtained from controlled cooking test (VITA 1982) are presented in Table 2. Each of the designs in pottery liners exhibits a potential for fuel saving over that in mud while all the models, irrespective of the material of the stove, performed better than the TC. The variation in performance of the *Mamta chulha* in mud in the laboratory and field is remarkable, the latter being less by 23%. In contrast to this, little variation is seen in the laboratory and field performance of the *Kiran*, *Varsha*, and *Mamta chulhas* in pottery. The superiority of these *chulhas* with prefabricated liners in pottery emerges clearly through this observa-

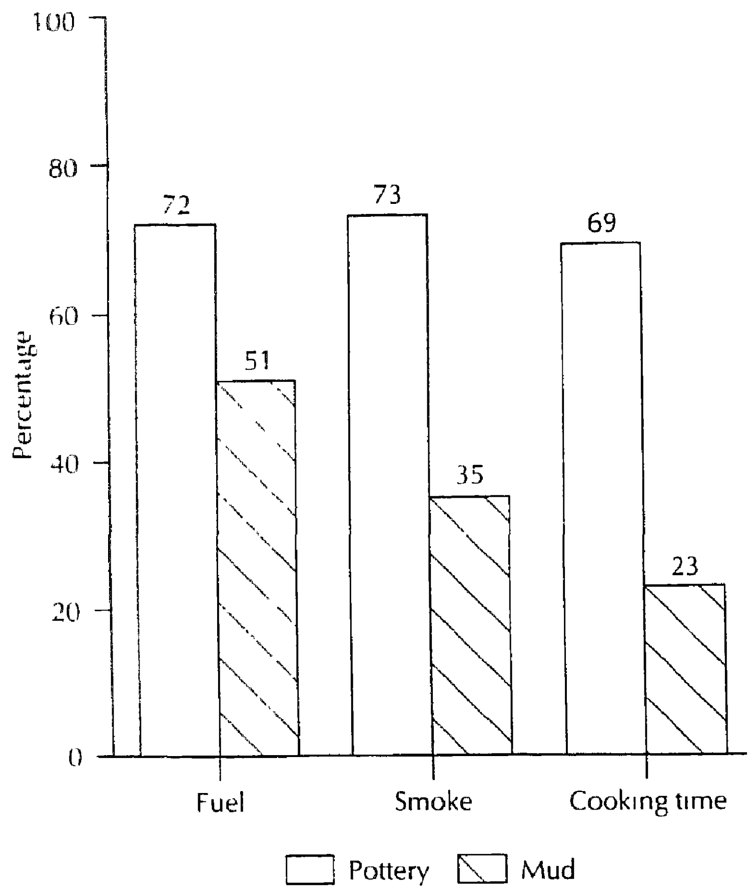


Figure 3. Perception regarding fuel saving, smoke in kitchen, and saving in cooking time

TABLE 1
Thermal efficiency of selected models of ICs and TCs

Name	Vessel size (cm)	Thermal efficiency (laboratory) (%)	Vessel size (cm)	Thermal efficiency (laboratory) (%)	Vessel size (cm)	Thermal efficiency (field) (%)	Difference in thermal efficiency between field and laboratory
Traditional rural *chulha*	36	24 00	24 5	17 9	—	—	—
Kiran chulha							
	36	25 20	24 5	20 0	—	—	—
	36	27.20	24 5	23 2	24 5	23.0	−0 08
Varsha chulha							
	36	26 14	24 5/22.5	23 0	—	—	—
	36	28 50	24 5/22 5	24.4	24 5/22 5	24 4	—
Mamta chulha							
	—	—	24 5/22.5	21.0	24.5/22.5	16 2	−22 85
	—	—	24 5/22 5	25.0	24 5/22 5	24 9	−0 04

TABLE 2
Fuel consumption and fuel-saving potential of selected models of ICs and TCs in cooking a standard meal (four items)

Name	Mass of cooked food (kg)	Mass of fuel consumed (kg)	Relative fuel saving of ICs versus TCs		SFC* (kg fuel/kg cooked food)	Difference in SFC of ICs versus TC		Cooking time per meal saved	
			kg	Percentage		kg	Percentage	Minutes	Percentage
Traditional Rural chulha	5 450	2 780	—	—	0 51	—	—	80	—
Kiran chulha									
Pottery	5.400	1.625	1.155	41 55	0 30	0 21	41.17	80	—
Varsha chulha									
Mud	5 575	1.345	1 435	51 61	0 24	0.27	52.94	60	25.00
Mamta chulha									
Mud	5.570	1 840	0.940	33 8	0.33	0 18	35 20	67	16.25
Pottery	5 920	1.000	1.780	64 02	0 17	0 34	66 66	60	25 00

* specific fuel consumption

tion. The fuel-saving potential of ICs with pottery liners thus do not depend on the SEW due to its being a standardized product which cannot be tampered with, in design details. The sample ICs in the field were nearly a year old and were tested in an 'as is where is' condition.

The controlled cooking test conducted on these ICs and TCs further substantiates the fuel-saving potential of ICs in comparison to TCs and that of pottery-lined ICs over mud ICs (Table 2).

Relative fuel consumption and fuel saving per *chulha* in comparison to TC is presented in Table 3. The estimations are made on the average fuelwood consumption on TCs per household at 10 kg per day. The yearly fuel consumption per *chulha* is computed by the relative merit of ICs over TCs based on thermal efficiency values. In the case of all the three improved stoves, the models in mud revealed higher consumption than those in pottery liners though both performed better than TCs. The fuel-saving per IC in pottery liner per annum was higher than that of the mud ICs. Assuming an average functionality rate of 60% for ICs installed in a given year, the annual fuel consumption and fuel saving are estimated. Table 3 reveals the potential of ICs in fuel saving at the micro and macro level and also the saving in fuel outlay possible thereof. If the functionality of ICs could be raised to as high as 100% through the promotion of prefabricated *chulha* liners and portable metal *chulhas*, the impact at micro and macro levels would be more remarkable. Further analysis to assess relative fuel saving of selected models of IC in pottery as compared to the mud ICs of the same design showed that the former exhibited greater potential to conserve biomass, the same being 18, 20, and 27% in the case of the *Varsha*, *Kiran*, and *Mamta chulhas* in pottery respectively. The yearly fuel saving, considering 60% functionality, was observed to be 9.75, 11 5, and 15% more in the case of ICs in prefabricated liners than those in mud (Table 4). These observations show empirically the greater potential of ICs in prefabricated liners of pottery as compared to the same model in mud. Similar findings would be relevant in the case of other models of ICs as well with the magnitude of saving

TABLE 3
Relative thermal efficiency and economics of operating selected ICs as compared to TCs

Name	Thermal efficiency (%)	Efficiency difference (%)	Yearly fuel consumption per *chulha* (kg)	Yearly fuel saving per *chulha* (kg)	At 60% functionality of ICs			
					Yearly fuel consumption (tonnes)	Yearly fuel saving (tonnes)	Percentage	Yearly saving in fuel outlay (Rs in lakhs)
Traditional rural *chulha*	17 9	—	3650 0	—	8 76	—	—	—
Kiran chulha								
Mud	20 0	11 73	3221 85 (730 00)	428 15	8 14	0 62	7 07	6 2
Pottery	23 2	29 6	2569 60	1080 40	7 20	1 56	17 80	15 6
Varsha chulha								
Mud	23 0	28 50	2609 75 (839 50)	1040 25	7 26	1 50	17 12	15 0
Pottery	24.4	36 31	2324 70 (890.60)	1325 30	6 85	1 91	21 80	19 1
Mamta chulha								
Mud	21 0	117.32	3017.80 (766 50)	632 20	7 85	0 91	10 39	9 1
Pottery	25 0	39 66	2202 40 (912 50)	1447 6	6 67	2 09	23 86	20 9

Note Figures in parentheses denote useful energy consumption in kg based on yearly consumption of 3650 kg fuelwood per household and thermal efficiency value of *chulhas*

TABLE 4
Intra-*chulha* comparison of fuel-saving potential of ICs

Name	Thermal efficiency (%)	Yearly fuel consumption per *chulha* (kg)	Yearly fuel saving per *chulha*		At 60% functionality of ICs			
			(kg)	Percentage	Yearly fuel consumption (tonnes)	Yearly fuel saving (tonnes)	Percentage	Yearly saving in fuel outlay (Rs in lakhs)
Kiran chulha								
Mud	20 0	3221 85	—	—	8 14	—	—	—
Pottery	23 2	2569 60	652 25	20 24	7 20	0 94	11 5	9 4
Varsha chulha								
Mud	23 0	2609 75	—	—	7 26	—	—	—
Pottery	24 4	2324 70	516 1	18 14	6 85	0 41	5 65	4 1
Mamta chulha								
Mud	21 0	3017 80		—	7 85	—	—	—
Pottery	25 0	2202.40	815 4	27 02	6 67	1 18	15 03	11.8

varying from model to model The estimations are made using fuelwood as the form of biomass burnt in the rural kitchens.

Commercialization of improved cookstoves

The scope for commercialization of portable metal *chulhas* needs no emphasis and is self-evident by virtue of its being a tangible value-added consumer product. However, with reference to fixed *chulhas*, which are traditionally in mud, concerted and conscious efforts need to be made to bring home the potential for transforming these into consumer products with commercial viability and entrepreneurship. This is possible through prefabricated components in pottery or ceramicware or metal cladded pottery or ceramic *chulhas*. Studies at TBU, Baroda (1990–95), and George, Yadla (1995b) have shown that beneficiaries of NPIC with prefabricated components of ICs adopted it for its value as a consumer good and novelty. The chimney pipe of ICs in mud rarely gave it the status of a consumer good. Cost-sharing became a voluntary phenomenon. Further, speedy installation and assured fuel conservation by virtue of its standardized components complying to design specifications give these an edge over mud ICs which are far from the original design in the field due to faulty installation In addition, replacements can be made of the entire *chulha* set or part thereof as the case is with liners which is rather difficult in mud *chulhas*. The prefabricated components in pottery provide scope for permanent installations in brick or mud platforms enabling the user to make replacements of liners as per the need. ICs in brick platforms could be put to use within a few hours thus replacing TCs almost with immediate effect, as compared to those in mud which could be used after 10–15 days. Maintenance of ICs in pottery liners fitted in brick platforms is easier than those in mud. ICs in mud are prone to cracks and breakages of the bridge above the fuel feed inlet and tunnels. A vast difference exists in the aesthetic appearance of pottery liners of ICs and mud ICs Moreover, prefabricated pottery liners of such models as *Kiran*, *Varsha*, *Nilesh*, and *Sneha* are low-cost devices that are affordable even by households at the lowest rung of the socio-economic ladder. Subsidies cannot be viewed as a long-term strategy for the dissemination of ICs. To reach a sustainable stage in NPIC and biomass conservation, ICs, in part or in total, ought to be available and accessible to its users. Therefore, along with a subsidized programme, commercialization of ICs has to take place. Prefabricated components of ICs is a concept that should be capitalized to the maximum in this context.

Initiative for commercialization of ICs

As mentioned elsewhere in the paper, nearly all fixed ICs installed go out of use with the passage of time. The magnitude of target population yet to be reached includes those owners who have abandoned the use of ICs at any given point of time. In other words, such a large target population – over 100 million households – could be reached in the shortest

period only through the commercialization of RETs, here ICs being the RET under consideration. To achieve commercialization, first and foremost, the prerequisites like the transition of fixed mud models of ICs to a value-added consumer product, creation of entrepreneurship and market, material inflow and product movement, quality control, marketing strategies, channels of distribution, consumer demand, and so on, ought to materialize A pottery liner production unit as a self-employment venture, a small-scale unit, or a diversified entrepreneurship venture of a large-scale manufacturing unit of ceramicware, could be undertaken. Depending on the scale of production, product flow, and marketing management, the investment and profit margin would vary

Building entrepreneurship and entrepreneurs is an urgent need in this context. A 10-day entrepreneurship development programme may not achieve the desired goal. The potters, who have tremendous scope to enter into entrepreneurship in ICs, need to be mobilized, guided, and established. This is an important task lying ahead. Way back in 1989/90, TBUs had conducted skill development training programmes for potters. However, setting up of pottery production centres materialized in a very few cases due to financial constraints and due to the laxity in creating the infrastructure. The Khadi and Village Industries Commission, apart from other institutional financiers like the Indian Renewable Energy Development Agency, has also evolved a loan scheme for entrepreneurship ventures in non-conventional sources of energy which would be beneficial for the commercialization of ICs Both production and service oriented entrepreneurship ventures have scope under NPIC. Wide publicity campaigns should be undertaken to build awareness among the potential target group. An environment to attract small and big, new and established entrepreneurs to deal with ICs ought to be created through government initiatives like fiscal incentives, technical support, and so on.

The target group of ICs should be made to realize their value at the micro and macro level to create a demand for the same Through appropriate marketing strategies and the exploitation of various media and communication modes, the producers and promoters of ICs should aim at creating consumer demand for pottery liners. The market is very vast and the scope enormous. However, the market needs to be created as a ready market does not exist for RETs like ICs in pottery liners. Absence of a ready market demotivates large entrepreneurs to venture into it. Small-scale units often lack quality control and products wither away due to poor quality. Mechanisms need to be developed through a government initiative to ensure quality products that enhance fuel efficiency of stoves, health of inmates of the household, biomass conservation, and environment quality.

The IC liners should be launched as a commercial product bringing to the fore what it can and cannot do, as well as myths and realities surrounding it The technology needs to be refined and modified, and R & D efforts strengthened to achieve a low-cost quality product that can withstand thermal shock.

Dissemination of any of the stoves cited in this paper or any other viable model promoted under NPIC in prefabricated liners would open up employment opportunities. A service personnel like a self-employed *chulha* worker installing, repairing, and maintaining ICs would earn Rs 10 000 or more for every 500 ICs attended to. Similarly, a potter with a production capacity of 300 liner sets per month earns an annual net income of Rs 11 000. A dealer and an entrepreneur would reap higher returns This would lead to increased eco-

nomic empowerment as well as enhanced agricultural productivity, better health nutrition, hygiene, sanitation, and greater scope for acquisition of income generating skills. Thus, commercialization of the IC programme would lead to enhanced well-being at the micro level and better rural national economy.

A range of products to suit various tiers of consumers from low-cost to expensive, single pot to multipot, and moderate to high power rated ones need to be made available in the market on the basis of which purchase decisions could be made. Already, time-tested designs are available. The specific models ought to be registered and patented.

Having been once exposed to these stoves, the rural women and households abstain from accepting mud ICs and exhibit willingness to pay, no matter whether it is Rs 100 or more. ICs in liners complying with design specifications give an assured performance in the field. The replacements of ICs in part or as a whole, as and when needed at the household level should become a possibility in the near future, and then, and then only, biomass conservation would become a reality through NPIC. Any support extended in this direction would pay dividends in terms of better environment and quality of life as ICs in pottery are environment-friendly consumer products. Monitoring the implementation should be in-built even within the commercial programme. Appropriate policies should be evolved by the government.

Conclusion

Biomass will remain the main cooking fuel to millions of households for years to come. The majority of such households are not self-motivated enough to adopt ICs for their own good, or for the common good of mankind, or to save micro and macro level economies. Conventional stoves can be easily set up without any technical skill in the absence of infrastructure for ready availability and accessibility to ICs. RETs like ICs and biomass generation are valuable options available to exercise effective management in domestic cooking for survival. The time is not ripe yet for the government to withdraw from the IC programme, which is relevant even for the poorest of the poor households in the country besides other segments. A differential subsidy programme may be adopted if not a uniform rate of subsidy until this becomes a totally commercial programme. Fiscal incentives like soft loans, tax benefits and the like need to be extended to entrepreneurs to woo them into entrepreneurship in ICs. A line of producers, traders, trouble-shooters, user educators, and consultant cells should emerge to form a product–service dissemination network.

An adequate publicity network should supplement and enhance the process of change. The environmental threats due to global warming from 'greenhouse' gases like CO_2 soot, dust and particulates, and ozone layer depletion can be checked through RETs. A deterrent in this direction is the low level of public awareness leading to the low acceptance of these options. Political will is imperative to create a conducive environment for the promotion of RETs like ICs. The policy directions of the government should be guided by the wide variations in household energy consumption patterns across regions and categories of households. The existing energy system is inequitable and affects the poor adversely. Policies that disfavour such inequity and unsustainable energy practices ought to

be drawn and implemented effectively. Reduction in imports of oil should be the underlying principle in chalking out policies. Such an approach calls for a larger scale of RET promotion than what is evident currently. Supply and demand management approaches are important to combat the energy crisis. Of special significance in this context is the commercialization of NPIC. However, the process of commercialization should be handled carefully to ensure that RETs, like ICs, are not wiped out totally from the society in the absence of subsidies.

The goal of rural sector to reach energy self-sufficiency, supported by RETs like ICs, requires, therefore, commitment, good leadership, and the cooperative efforts of designers, planners, consumers, extension personnel, service units, and producers.

Acknowledgements

The author places on record the support received from MNES, the *Panchayat* and Rural Housing Development Department, Government of Gujarat, and the Development Office, Government of Gujarat, that made it possible to undertake R & D work and field work on ICs under the aegis of TBSU–NPIC, Home Management Department, MS University of Baroda. The MS University of Baroda is also duly acknowledged for facilitating the work through the provision of infrastructure.

References

George R. 1986. *Thermal efficiency of innovative cookstoves* (Mimeograph). Baroda: The Home Management Department

NCAER. 1993. Evaluation survey of the National Programme on Improved *Chulha* Final Report (Volume 1) New Delhi. National Council of Applied Economic Research

TBSU–NPIC. 1990/91–1995/96 Annual Reports. Baroda: Technical Backup Support Unit–National Programme on Improved *Chulhas*, Home Management Department.

George R, Yadla V L 1995a Adoption of a selected model of improved chulha by rural families. Baroda The Home Management Department

George R, Yadla V L. 1995b. Biomass conservation potential of pottery/ceramic lined mamta stove· an improved stove promoted under the National Programme on Improved *Chulha* in India *In* NSEC (ed) *Proceedings· Solar 95 – National Solar Energy Conference* 15–20 July, Minneapolis, Minnesota

VITA. 1982 *Results of the Controlled Cooking Test* Arlington, Virginia. Volunteers in Technical Assistance

THERMAL-EFFICIENT METAL COOKSTOVES WITH WATER HEATING ARRANGEMENT FOR COLD CLIMATES

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Introduction

The state of Himachal Pradesh (HP) is situated in the heart of the north-western Himalayan region and lies between 30°22' to 33°12'N latitude and 75°45' to 79°04' E longitude. HP is divided into four climatic zones: (i) the cold dry temperate zone with an altitude above 2200 m; (ii) the temperate wet zone with an altitude range of 1840–2200 m; (iii) the sub-temperate zone having altitude in the range of 651–1840 m; and (iv) the sub- tropical zone having altitudes below 651 m.

The temperate wet zone, which constitutes 32.5% of the total geographical area of HP, includes parts of Shimla, Chamba, Kullu, Mandi, Kangra, Sirmour, and Solan districts. This region generally records 138–150 cm of rainfall annually, mostly during the period from July to September. The minimum and maximum temperatures of the region are: –10 °C and 29.4 °C, respectively The region also receives snowfall and ground frosts from November to March, and the average snowfall is 150 cm. The weather remains cold during this period, and an average 2500 chilling hours with temperatures below 7.2 °C are recorded. Space and water heating are major requirements. As power failures are frequent during winters, wood and coal metal stoves are used in the high altitude regions of this zone and three-pot mud fixed cookstoves are being used in other parts of the zone.

The state has a high per capita energy consumption, which is nearly double that of the north Indian average. The average per capita fuel consumption ranges from 1257 kg in the Pooh block of Kinnaur district to 480 kg in Solan district. Figures for other districts falling in this zone are 1091 kg in Mandi and 980 kg in Shimla. Generally, no wood is purchased in the rural areas of the state. It is estimated that 3–6 person hours per day per household

are spent mostly by women in collecting the fuelwood. People also use agrowastes, bushes, trees, and pruned wood to meet fuelwood requirements. However, the forests generally have to bear all this pressure. As a result, the biofuel energy situation has deteriorated in the state. Agricultural residues and, to a very limited extent, cowdung are also used as cooking fuel.

To assess the basic requirement of the people and identify the design parameters of the traditional cookstoves being used in the region, a need-based survey was carried out by the Technical Back-up Support Unit (TBSU) for HP established in 1988 by the Ministry of Non-conventional Energy Sources (MNES) under the National Programme on Improved *Chulhas* (NPIC) at the Dr Y S Parmar University, Solan. The survey results of traditional stoves revealed the following.

- A three-pot fixed mud cookstove without a smoke pipe is used in the lower parts, and a metal cookstove with water heating arrangements fitted with pipe in high altitude regions.
- The size of the cookstoves and pots varies from house to house.
- The cookstove is hollow from inside, with no tunnels, grate, and any arrangement for proper smoke emissions. The mud stoves are made of stones, clay, and cowdung, while, in some other cases, they are made of only stone. These are placed on the floor. In some houses, it is located under the chimney hood. The metal stove is made of 16–18 SWG sheet, fabricated by local artisans. The cost of the stove depends upon the size of the stove and thickness of the SWG sheet being used, and varies, generally from Rs 500 to Rs 1500.
- Space heating is the main requirement apart from cooking and water heating during the winters, and, for this purpose, the firebox is kept large and is dug 5–6 cm deep into the floor so that burnt charcoal and ash remain there for a longer period. This is also required for baking maize *roties* which are thick and large in size. The whole family sits around the cookstove in winters. In some places the top of the firebox in a mud cookstove is not constructed or is broken off, especially in *brahmin* families because of religious beliefs. The cooking efficiency of these stoves is between 8 and 13% and also causes health hazards.

The state energy development agency, Himurja, has given the task to TBSU of improving the thermal efficiency of the metal stove provided with the water heating arrangement and, determining the water and space heating efficiency of the model. TBSU is also a testing and certifying centre of the MNES for improved cookstoves and is likely to be identified as an ISI laboratory by the Bureau of Indian Standards (BIS)

Based on a survey of traditional cookstoves, an improved metal wood-burning cookstove with a water-heating arrangement has been designed and tested.

Characteristics of the improved cookstove

The dimensions of the stove are: length 68 cm, breadth 35 cm, and height at front 24 cm and at back 28.5 cm. The size of the firebox is 19 × 13.6 cm. The pot size is designed to adjust to the utensils of all sizes. The grate is made of 16 SWG sheet, with small holes of

equal size for air circulation, and has a little upward slope. A plate is provided at the bottom to remove the ash. An upward slope from the grate to back pots is also provided that flame touches the utensils, as well as downward slope from the back pots to the chimney, which would reduce the heat loss through the chimney A water tank is provided inside the cookstove, with a capacity of 30 litres. This is in direct contact with the combustion chamber A steam pipe must be provided in the stove of length equal to the chimney pipe with a cap at the top to stop the rains water from coming into the pipe This will also increase the room temperature. However, a steam pipe was not used in this model as it is used for a shorter duration. The stove has one inlet at the top for cold water and one tap for hot water (Figure 1).

Thermal performance test

The stove was placed in the middle of a room made of concrete and cement with area of 10 × 8 × 8' The room had two glass windows and a door of size 6.5' × 3' × 1" The eucalyptus wood was used as fuel having a calorific value of 3800 kcal/hour and a wood burning rate of 1.3 kg/hour. The water boiling test prescribed by MNES was followed to calculate the cooking and water-heating efficiencies of the stove. The space-heating efficiency was calculated using the heat gain and heat loss due to convection, conduction, and radiation

The temperature variation in the room, the water in the tank, the water in the utensils, and the ambient temperature were recorded by digital temperature indicators

Results and discussion

The results reveal that the stove has a cooking efficiency of 18 7%, which is less than the 20% prescribed by MNES The low efficiency is due to the fact that water is in direct contact with fire Part of the heat produced by wood is utilized for water heating, and the rest is used for cooking and space heating The power output rate of the stove is 1.08 kW which is equivalent to power output rate of a gas burner Table 1 shows that the temperature in

TABLE 1
Variations in temperature

Time (minutes)	Temperature (°C)		
	Water	Room	Ambient
0	12	9 40	10 5
10	19	10 40	10 5
20	26	12 25	10 5
30	40	12.00	10 5
40	52	14.00	11 0
50	62	15.60	11 0
60	72	17 00	11 0



Figure 1 Wood-burning metal cookstove with a water-heating arrangement

the water tank increased from 12 to 40 °C within 30 minutes after the stove was lit up and a temperature difference of 70 °C was obtained after one hour. The water-heating efficiency of the stove was 40.75%. The 30 litres of water with a temperature of 82 °C can be utilized for washing and bathing. In addition, it also increases the room temperature from 9.4 to 17 °C within one hour consuming only 1.3 kg of wood. The space-heating efficiency

works out to be 29.43%, with the total thermal efficiency at 88.38%. The results are summarized in Table 2. The variations in the cooking efficiency and in the power output rate of the stove are shown in Figures 2 and 3, respectively. The temperature variations are given in Figure 4.

TABLE 2
Results of the water boiling test

Parameter	Pot 1	Pot 2	Pot 3	Total
Efficiency (%)	11.76	4.52	2.42	18.70
Power output rate (kW)	0.68	0.26	0.14	1.08

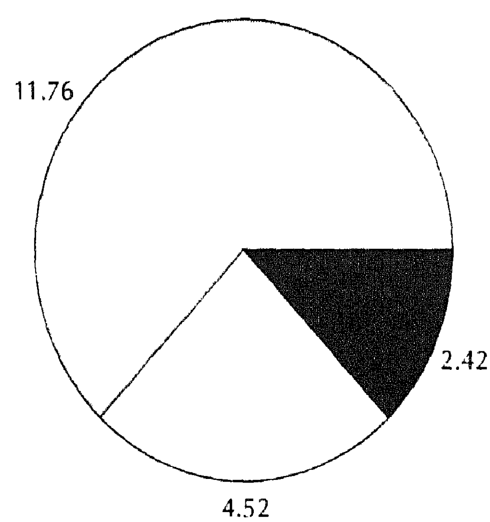


Figure 2. Efficiency distribution of the first, second, and third pots (%)

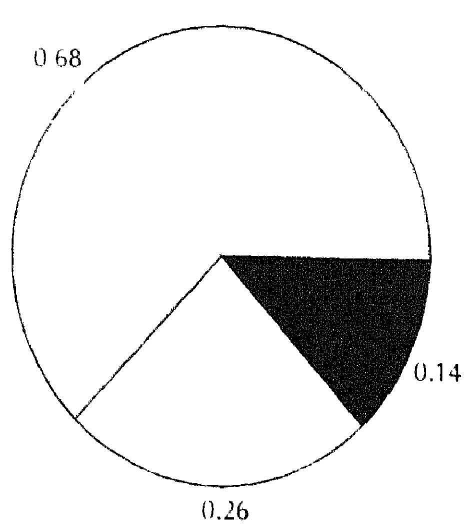


Figure 3. Power output rate distribution of the first, second, and third pots (kW)

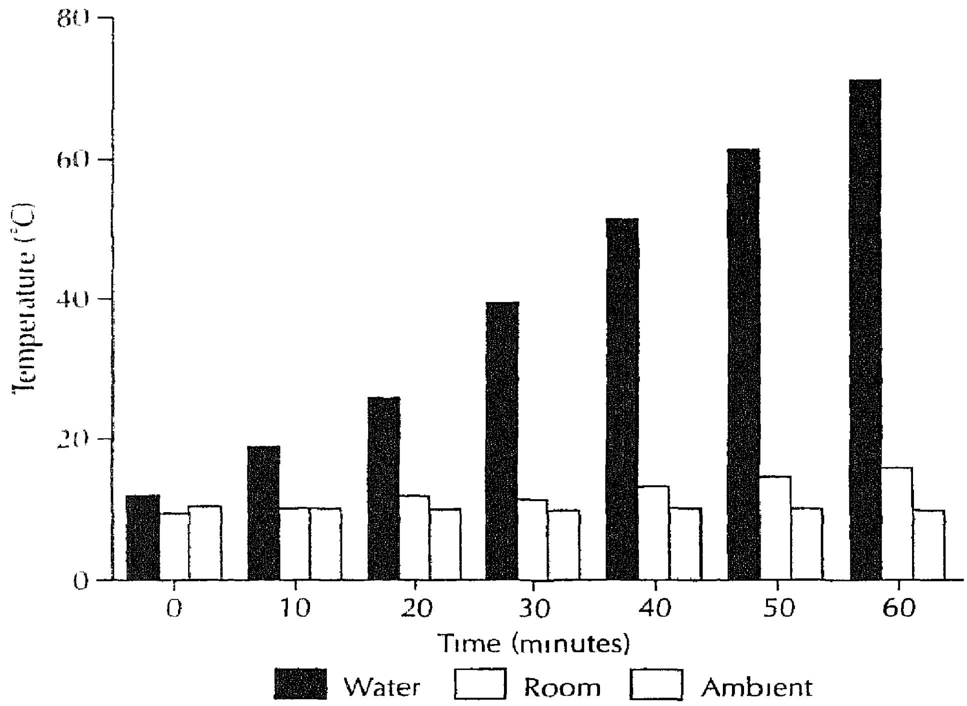


Figure 4. Variations in room, water, and ambient temperatures

Conclusions

This stove meets the basic requirements of cooking and water and space heating, and utilizes fuelwood to the maximum extent However, there is scope for improvement in the design of the stove to increase its cooking efficiency up to 20%. The model is in great demand not only in the higher ranges, but also in other parts of the state. It is likely to be approved by MNES for propagation on a subsidized rate not only in HP, but also in the other hilly areas of the country. This model has reduced the fuel consumption from 5 kg/hour to 1.3 kg/hour thereby reducing the burden on forests. The manufacturers, who fabricate the high-altitude metal stoves, have approached this centre for the fabrication and propagation of this model. One thing has, however, to be kept in mind: carbon soot from the smoke pipe must be removed within a week's time, otherwise the pipe will get choked, and the stove will not function properly. The cost of the stove is Rs 600, out of which MNES will provide a subsidy to the tune of Rs 250. The model can be adopted by one lakh families in HP. Some of these families can buy the stove even without the subsidy, as they already spend Rs 500–1500 for purchasing the metal stoves from the local artisans The life of the stove is about 10 years if 16 SWG sheets are used.

The adoption of this thermal-efficient improved stove will lead to savings in the time and energy needed for fuelwood collection. This is particularly so for the rural women who share much of the burden of meeting the household energy needs These savings in time and physical energy can be better utilized in different farm and off-farm activities It will

also reduce smoke pollution in the house, thereby improving the health of the family members. Again, women and children, who are exposed to such an environment for longer durations will benefit significantly.

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FUEL USAGE IN DELHI SLUMS AND EXPOSURE TO AIR POLLUTION

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Introduction

It is well known that rapid industrialization and urbanization have led to a deterioration of environmental conditions. In urban areas, poor sanitation, generation of solid wastes, and inadequate housing and water supply are acknowledged causes of ill health. What is less well known is that the traditional domestic practice of cooking in primitive stoves with low grade fuels and in badly ventilated kitchens can have serious implications for the health of women and children (Smith 1987). In rural areas, women and children are exposed only to pollutants from such combustion. However, their counterparts in urban slums are additionally exposed to pollution from industrial and vehicular sources because slums are commonly located near factories and highways. Thus, it would appear that the urban slum community bears the largest air pollution exposure burden in developing countries. A number of studies have attempted to estimate the exposure from biomass combustion in rural areas of India, Nepal, and a few countries in Africa (Smith, Aggarwal, Dave 1983, Ramakrishna 1988, Menon 1988, Pandey, Neupane, Gautam 1987, Saksena *et al.* 1992). However, the information related to the urban situation is meagre (Smith *et al.* 1994, Raiyani *et al.* 1994).

It has been postulated that household fuel switching from lower to higher quality fuels, i.e., movement up the 'energy ladder', generally leads to substantially lower emissions of health-damaging pollutants. The extent to which exposures are reduced is difficult

to predict, specially in urban areas, because of the presence of both indoor and outdoor sources.

Generally, people evidently move up the energy ladder when they have the opportunity to do so. While roughly half the world has moved upwards (with respect to wood), the other half is still at the same stage or has been forced to move down to inferior fuels

While at the household level the financial implications of shifting to better energy systems may not be significant, considering the large populations of countries in the developing world, the macro-level implications are indeed astronomical. Coupled with the limitations of availability of alternatives and associated infrastructural and institutional requirements, the policy issues are of serious concern to decision makers and planners. Before embarking on new national policies or technical initiatives, there is a need to gather extensive scientific evidence. Some questions that are of interest here are listed below.

- How clean are clean fuel stoves?
- Are clean fuel stoves the sole guarantee to a better energy–environment situation?
- What would be the energy–environment implications of the rural–urban migration at the micro and macro levels?

It is in this context that TERI conducted a series of empirical studies, the latest being the study described in this paper The study is of special interest because of the paucity of information regarding the urban slum situation and possible complex interactions between indoor and outdoor air quality and housing conditions in slums.

Objectives of the study

The study aims at objectively testing the hypothesis that exposure to high levels of respirable suspended particulates (RSP) increases the risk for acute lower respiratory Infection (ALRI) among infants The intermediate objectives of the study are

- to estimate the daily integrated exposure of infants to RSP in winter;
- to measure the incidence rate of ALRI in infants, during the same period, and
- to measure association between exposure to RSP and ALRI incidence.

The secondary objectives of the study include:

- the estimation of the daily exposure of the mothers of the infants to RSP;
- the study of the fuel usage patterns in selected slums; and
- the gathering of data on basic household information and baseline health status

Description of the study area

According to a survey conducted by the Delhi Administration in 1991, there are more than 1000 slum clusters in Delhi. These are called *jhuggi-jhopri* (JJ) clusters. While slum-like

conditions exist in about 50% of Delhi's population, the JJ clusters account for 10% of the total population. The decade between 1971 and 1981 saw a 200% increase in the supply of fuelwood in Delhi. However, after 1981, there has been a steady decline. Ration cards for kerosene supply were issued in 1991 to most slum dwellers; after that the fuelwood consumption decreased drastically. Right now, Delhi has the highest per capita consumption of kerosene among the cities of India. The per capita consumption of fuelwood is higher in slums in south and west Delhi (TERI 1993). In surveys conducted before actual sample selection, it was observed that Muslims and Rajasthanis prefer to use wood for traditional reasons.

Delhi is the fourth most polluted mega-city in the world *vis-à-vis* air quality (particulate matter). More than three-quarters of the emissions of air pollutants are caused by vehicles. There are about 94 000 small- and medium-scale industries in the city and three thermal power plants – all coal-based.

Study design

Two large slums (more than 4000 households) were chosen – one in west Delhi (Kathputly colony, a highly polluted area) and the other in south Delhi (Kusumpuri Pahari, a less polluted area). These were selected after reconnaissance surveys were conducted in 50 slums. These surveys gathered information on the total number of households; the number of households using fuelwood and kerosene; the distance of the slum from industrial complexes, major roads, and the nearest ambient air quality monitoring station; and the type of houses. In both the slums, 160 houses were chosen (with infants), each in the fuelwood and kerosene category. In these houses, medical, demographic, and social surveys were conducted. In a sub-sample of 80 houses, the daily exposure to RSP was estimated All surveys were conducted simultaneously in winter (December 1994 to February 1995) From an epidemiological point of view, this study is essentially of the prospective cohort type Data were collected and analysed in the stratified random sampling framework

Methodology

Recall survey methods were used to collect data on basic household information and time budget studies. A single top pan weighing balance (of 50 g least count) was used to survey fuel usage patterns along with a digital stopwatch. Health data were gathered using the National Acute Respiratory Infection Control Programme and World Health Organization criteria.

The assessment of daily exposure entailed measuring concentrations of RSP in important micro-environments and obtaining information through recall surveys on time spent by infants in these micro-environments. Preliminary surveys aided in identifying the optimum number of micro-environments necessary for estimating daily exposure Thus, six micro-environments were finally selected: (i) cooking area during the preparation of breakfast; (ii) living room when no cooking is going on, (iii) outdoor, near the house,

when no cooking is going on; (iv) cooking area during the preparation of lunch; (v) cooking area during the preparation of dinner; and (vi) living room after dinner. While the second, third, and sixth micro-environments are common to all households, without exception, the existence of the other three micro-environments depends on the cooking practices of individual households. A suitable surrogate, from among these six micro-environments, was found for micro-environments not covered otherwise. For example, if the infant's mother takes it along to her place of employment, then the third micro-environment was substituted, because it was not feasible to take measuring instruments to all places visited by the mother.

Area sampling was done in all the micro-environments using low-flow pumps. Inherent in this is the assumption that spatial variation of concentrations is not significant under the given conditions. The entire duration of the cooking micro-environment was sampled, because of the obvious minute-to-minute variations in levels. However, since such variations are not significant in the other micro-environments, only a part of their duration was sampled.

The daily integrated individual exposure was computed as follows:

$$E_i = \sum_{j=1}^{6} C_{ij} t_{ij}$$

where E_i is the daily integrated exposure of the *i*th infant (mg-h/m^3), C_{ij} is the concentration of RSP in the *j*th micro-environment of the *i*th infant (mg/m^3), and t_{ij} is the time spent by the *i*th infant in the *j*th micro-environment (h).

Results

The results of measurements related to cooking energy are shown in Table 1 It was observed for wood users that there were statistically significant differences in fuel consumption between the two slums ($F = 11$, $p < 0\ 002$). The difference between the two slums with respect to kerosene consumption is not significant. The reason for this is perhaps the cultural preference of the Rajasthani community, which is a majority in one of the slums, for cooking extensively with wood. The per capita consumption of wood seems lower than

Table 1
Cooking energy consumption patterns in the two slums

Fuel category	Slum location (air quality)	Number of meals cooked in a day	Daily time spent in cooking (hours)	Burn rate (kg/hours)	Fuel use (kg/capita/day)	Useful energy consumption (kcal/capita/day)
Wood	High	1.4	1 70	1.42	0.40	222
	Low	2.0	2.20	1.33	0 60	336
Kerosene	High	1.9	2.20	0.16	0.06	263
	Low	2.4	2.10	0.16	0.08	321

Note. n = 20, each group; coefficient of variation = 30–50%.

that reported earlier. The possible reasons for this are: (i) the data reported here are based on actual measurements, whereas earlier surveys relying largely on recall methods tend to overestimate consumption, and (ii) communities with lower purchasing power tend to cook fewer number of meals, have less access to food and fuel. A tendency has also been observed in slums towards buying partly or fully cooked food.

The per capita useful energy consumption was found higher in houses that use kerosene. This may be explained by the fact that a shift towards kerosene also reflects increasing purchasing power, which, in turn, may also lead to cooking more food, more meals, or types of foods that require longer cooking times.

We observed that 55.7% of wood users also own a kerosene stove, and 44% of kerosene users also own wood-burning stoves. While 72% of wood-using houses are electrified, this is true of 80% of the kerosene-using houses. But the difference is not statistically significant ($\chi^2 = 4.3$). However, the difference between the two slums was significant in this regard ($\chi^2 = 154$, $p < 0.00001$). In Kathputly colony, 97% of the houses were electrified and, in Kusumpuri Pahari, 54% were electrified.

Table 2 highlights an interesting phenomenon – cultural preferences may be so strong that some families possessing a ration card (thus with access to kerosene) may still prefer to use wood. Hence, policymakers must keep in mind that providing people with ration cards cannot alone promote the use of kerosene.

That the location of cooking is dependent on the type of fuel is brought out in Table 3. This aspect strongly influences the exposure patterns as does the time-activity patterns of women and infants (Table 4). It was observed that the actual fraction of time spent near the fire by infants is 62% for wood users and 81% in case of kerosene users. The daily exposure patterns of infants and their mothers to RSP are illustrated in Figures 1 and 2 respectively. In the highly polluted slum area, the difference between the two fuel groups was very significant. This is perhaps because of the tendency of certain ethnic groups residing there to keep fires on for a very long time. In the other slum, it was observed that both fuel groups are exposed to similar levels of RSP pollution. Kerosene users tend to cook indoors, keeping their infants also indoors. But wood users mainly cook outdoors, and depending on the season they may keep their infants indoors or outdoors. Thus, at least for infants, it is very likely that there is considerable overlap of exposure levels between the two groups.

TABLE 2
Relationship between possessing ration card and fuel type

Fuel	Percentage of houses with ration card	
	Yes	No
Wood	95.6	4.4
Kerosene	89.2	10.8

Note $\chi^2 = 9.3$; $p < 0.005$.

TABLE 3
Location of cooking with respect to fuel type

Season	Percentage of houses cooking indoors		Statistical significance
	Wood	Kerosene	
Winter	65.5	93.4	$\chi^2 = 66$ $p < 0.00001$
Summer	32.5	69.1	$\chi^2 = 80$ $p < 0.00001$
Monsoon	91.6	97.7	$\chi^2 = 10$ $p < 0.00001$

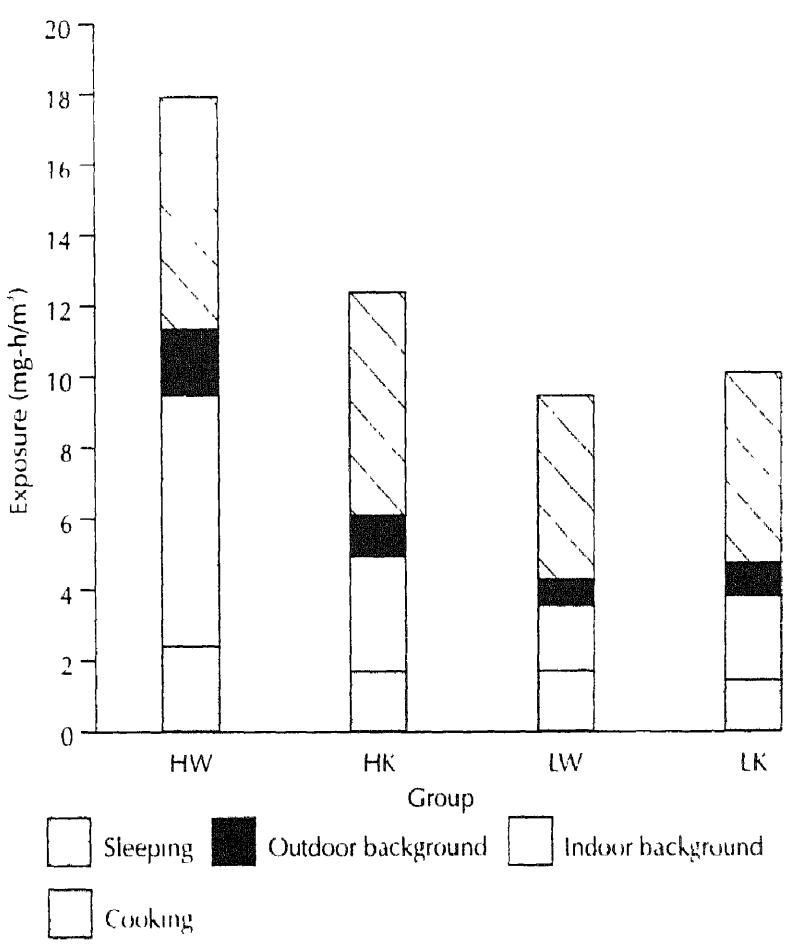


Figure 1. Daily exposure of infants living in slums to RSP; H: high; L: low; W: wood; K: kerosene (high and low refer to ambient air quality)

TABLE 4
Time spent in various micro-environments by women (and their infants) (hours)

Fuel	Slum location (air quality)	Micro-environment			
		Cooking	Indoors	Outdoors	Sleeping
Wood	High	2.4	5.4	7.5	8.8
		(1.5)	(9.9)	(4.6)	(8 0)
	Low	2.6	5.1	7.8	8.4
		(1.6)	(8.6)	(4.7)	(9.1)
Kerosene	High	2.7	5.2	7.8	8.4
		(2.3)	(8.7)	(4.4)	(8.6)
	Low	2.6	5.2	7.4	8.8
		(2.1)	(8.3)	(4.7)	(8.9)

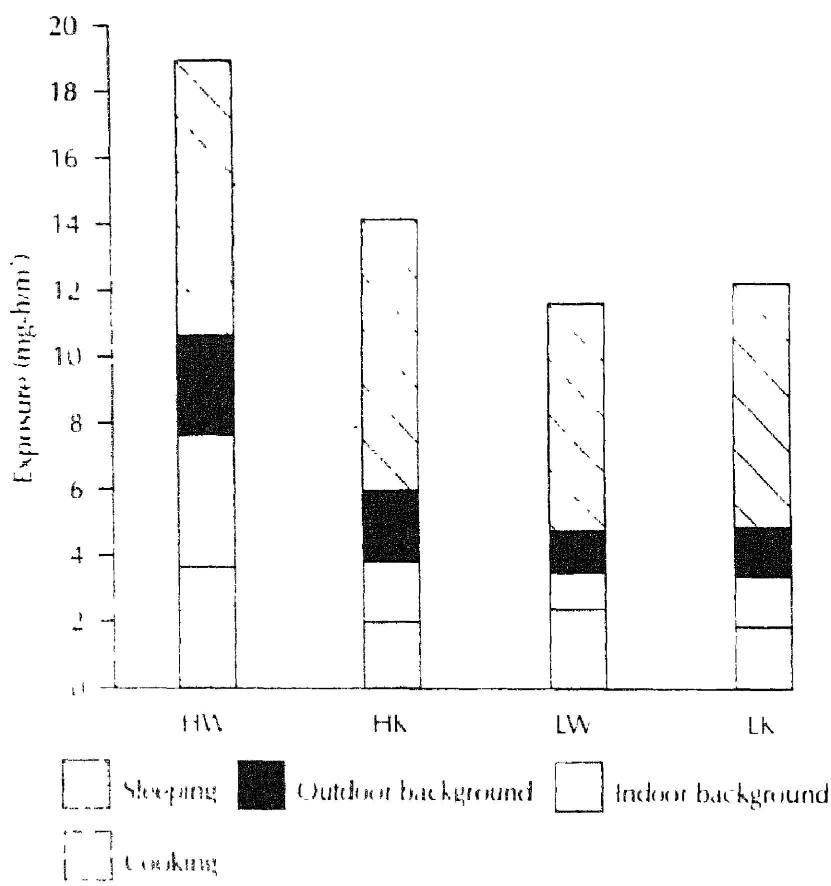


Figure 2. Daily exposure of infants living in slums to RSP; H: high; L: low; W: wood; K: kerosene (high and low refer to ambient air quality)

While the upward shift towards a cleaner fuel (kerosene) may reduce the exposure, this effect is perhaps being countered by the effect of shifting to a less ventilated environment and the effect of increased duration of cooking

Conclusions

This study has shown that apart from fuel type there are at least three other factors that strongly influence exposure

- ventilation – housing type and location of cooking;
- behavioural patterns induced by a change in purchasing power/affluence, and
- cultural practices

The daily exposure of infants and women living in slums exceeds that of people living in rural areas. Also, in urban slums, the share of outdoor sources of pollution is also significant compared to indoor sources.

In future, it would be essential to use the intervention type of studies to conclusively test the relationship between exposure and health impacts. Large-scale epidemiological studies are needed in rural and urban areas to aid informed decision-making. Finally, the fuel supply and demand situation in slums needs to be examined in greater detail, through scientifically designed surveys, keeping in mind economic, social, and environmental considerations.

References

Menon P 1988 Indoor spatial monitoring of combustion generated pollutants (TSP, CO, B(a)P) by Indian cookstoves PhD Thesis Honolulu. Department of Meteorology, University of Hawaii

Pandey M R, Neupane R P, Gautam A G 1987 Domestic smoke pollution and acute respiratory infection in Nepal In Seifert B *et al* (eds) *Proceedings of the Fourth International Conference of Indoor Air Quality and Climate* 4: 25–29 Berlin, FRG Institute for Water, Soil and Air Hygiene

Raiyani C V, Shah S H, Desai N M, Venkaiah K, Patel J S, Parikh D J, Kashyap S K 1993. *Atmospheric Environment* 27A(11): 1643–1655

Ramakrishna J 1988 Patterns of domestic air pollution in rural India. PhD Thesis. Honolulu Department of Geography, University of Hawaii

Saksena S, Prasad R, Pal R C, Joshi V 1992 Patterns of daily exposure to TSP and CO in the Garhwal Himalaya *Atmospheric Environment* 26A(11) 2125–2134

Smith K R, Aggarwal A L, Dave R M 1983 Air pollution and rural biomass fuels in developing countries *Atmospheric Environment* 17(11) 2343–2362

Smith K R, Apte M G, Yuqing M, Wongselziarttirat W, Kulkarni A 1994 Air pollution and the energy ladder in Asian cities *Energy* 19(5): 587–600

Smith K R 1987 *Biofuels, Air Pollution, and Health. A Global Review* New York Plenum Press

TERI. 1993 Study of the energy needs of slum areas in Delhi Final Project Report submitted to the Delhi Energy Development Agency New Delhi: Tata Energy Research Institute

IMPROVED COOKSTOVES FOR BIOMASS CONSERVATION IN THE CENTRAL HIMALAYAN REGION

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Introduction

Rural households depend primarily on biomass energy. Due to the acute shortage of biomass energy (fuel fodder), people in the Himalayas are still at the subsistence economy level and are faced with the problem of dwindling biomass resources every year. About 90% of the rural household energy demand is met by fuels like cattle dung and firewood. Due to the pressure on rapidly depleting biomass reserves, improved cookstoves (ICs) have attained strategic importance in the last two decades. Since the majority of the rural households depend on biomass cookstoves for cooking, any improvement in their performance will have an immediate beneficial impact on the biomass situation and fuel procurement practices of the user

In this paper, the issues involved in dissemination and monitoring of ICs have been discussed The results of measurements conducted in the field to assess the energy savings achieved due to the use of ICs are also presented.

Study area

The study was conducted in four villages in the Garhwal district of central Himalayan region The maximum altitude in this district is 3098 mt while the highest village is located at 2480 mt The area has a sub-temperate to temperate climate, which varies respectively

from very cold and dry to humid temperatures. As a response to climatic variations and local availability of building material, many different types of dwellings are found in the district. The climate depends to a large extent upon local factors and can vary considerably within a few kilometres (Joshi *et al* 1991).

The transport of materials involves much greater labour here than in the plains, and, consequently, traditional buildings in the hills are constructed almost entirely of the locally available material. The dwellings are designed to provide adequate protection from severe winters.

The characteristic features of the monsoon climate of the slopes lying south of the main range of Garhwal Himalaya are comparatively small temperature differences within the annual cycle, high rainfall in summer, and high humidity in the valley throughout the year

The study villages are located at the height between 1300 m and 1500 m elevation in Garhwal district, and support tropical and sub-tropical forests. The dominant shrub species are *Rhus-parviflora, Capparis sapiaria, Ziziphus, Berberis*, etc The main tree species are Pine and oak (Prasad, Sharma, Joshi 1994) Table 1 shows the profile of the villages studied.

All the villages are situated on hill slopes. There are primary schools in every village and a higher secondary school in the radius of 2 km Though agriculture is the main occupation, a number of persons are engaged in tertiary services like teaching in nearby places or towns. The level of literacy among women is high compared to other parts of the country

Energy consumption pattern in the study villages

Two energy studies (Joshi *et al.* 1991; 1994) were conducted to understand the traditional cooking systems in the study area. Table 2 shows the per capita per day fuel consumption in different villages. Ghiri village has the highest per capita/day biomass consumption followed by Kadola and Marora villages.

TABLE 1
Profile of the villages studied

Village	Number of households	Total population	Total area (ha)	Forest (ha)	Cattle	Electrified	Distance from road (km)
Marora	13	68	143.18	8.83	72	Yes	3.0
Ghiri	45	218	56 62	2.46	162	Yes	0.5
Kadola	17	101	35.11	10.73	148	Yes	1.5
Chrindalu	19	95	26.60	9 20	86	Yes	0 5
Nautiyalgaon	28	129	18.10	0 20	92	Yes	0.5

Sources. Prasad, Joshi (1992); Prasad, Sharma, Joshi (1994)

TABLE 2
Energy consumption pattern in the Garhwal villages (kg)

Village	Per capita/day fuelwood consumption	Per capita/day dungcake consumption
Agrora	1.08 ± 0.65	0.28 ± 0.22
Ghiri	1.92 ± 0.71	0.20 ± 0.19
Jaspur	1.21 ± 0.32	0.20 ± 0.20
Kadola	1.86 ± 0.82	0.06 ± 0.01
Nautiyalgaon	1.10 ± 0.65	0.30 ± 0.11
Marora	1.85 ± 0.72	0.02 ± 0.01

Source. Joshi *et al.* 1994.

Cooking energy system in study villages

The main components of the cooking energy system in a typical household in Garhwal are. (i) kitchen, (ii) cookstove, (iii) cooking vessels, (iv) food items, (v) fuel, and (vi) cooking practices.

The kitchen is generally located on the ground floor and the ceiling height is approximately 5–6 feet. The commonly used cookstoves are the traditional two-pot mud cookstove fixed in the kitchen and the kerosene stove Flat and round bottom pots made of brass, aluminum, iron and stainless steel are used Twigs of local shrubs are the main fuel used in these villages. Villagers also use dungcakes almost throughout the year except in monsoon months The main crops of the region are wheat and barley in the *Rabi* season and paddy and pulses in *Kharif*. Rice and *roti* are the staple food items. Meals in a household are cooked thrice in summer and twice in winter. The time spent on cooking is around four to five hours daily

Dissemination of the improved cookstoves

The Ghiri, Nautiyalgaon, Kadola, and Marora villages were selected for the installation of the two-pot fixed ICs (*Abhinav*) model as an alternative to the traditional fixed stove in the kitchen Though there were other models, *Abhinav* was well developed with enough flexibility in the design to make it user-friendly. In the beginning, a few stoves were installed free of cost, which received a good response from the study villages and from other nearby villages as well Eventually a group of men and women were trained and about 92 more stoves were installed in four villages with the help of three trained persons Each beneficiary paid Rs 15 which was deposited in the account of *Mahila mandal dal* in the each village For the maintenance and monitoring to ensure the proper use of the stove, a trained technician would visit each household once in a week to ensure that the ICs are being used and the users are capable of solving minor maintenance problems. The IC

dissemination programme started with demonstration and training in villages. Two cookstoves were installed during the demonstration and training in each village. Women of the households played an active role in cookstove installation by collecting the mud, dung, and wheat straw, preparing construction material, and selecting the site for the stove in the kitchen. In these villages, some girls and boys who received IC construction training during the demonstration programme also installed a few ICs in the neighbouring villages.

Main findings

Evaluation of the improved cookstoves

A questionnaire-based study and actual experiments were conducted for the kitchen performance and water boiling test to know the status and thermal efficiency of improved stove as well as the traditional ones. The methodology followed in the study was similar to the one proposed by the volunteers in technical assistance (VITA 1985).

In all the four study villages, the fuel efficiencies in households using IC under field conditions relative to the traditional stove through the actual weighing method were estimated.

Status of improved cookstoves

The working status of ICs had been classified in different categories, namely (i) working and in use, (ii) not used at all, (iii) working but occasionally, and (iv) working during the winter season only.

It can be seen from Table 3 that only 54% of the ICs installed were found to be in working condition and also in use. Another 12% and 17% of the installed ICs were found to be in working condition but used occasionally and during the winter months due to cold climate, respectively. Only 17% of ICs were not used at all due to problems with the stove A section of these households was motivated to use ICs except in those cases where the households dismantled the stove or owned more efficient devices than ICs.

Benefits of improved cookstoves

One of the basic objectives of the dissemination of ICs was the reduction in the consumption of fuel, which was considered to be more fuel efficient than the traditional cookstove (TC). As depicted in Table 4, 84% households reported that it served as a smoke-removal

TABLE 3
Status of ICs in study villages

Responses	Frequency	Percentage
Working and in use	44	54
IC not used at all	14	17
Working occasionally	10	12
Working during winter	14	17
Total	82	100

TABLE 7
Results of the kitchen performance test in Ghiri village

	IC	TC
Number	22	14
DAEC in the range (MJ)		
Variation in average	27.42–109.77	31.95–116.88
Overall range	25.81–123 56	28.98–133.56
Range in maximum	23.07–123 56	33 67–133.56
Variations within a family		
Maximum	94 70–123 56	40.12–87.42
Size of family	1	2
Minimum	40.44–43.56	29.49–33.67
Size of family	5	4

Conclusions

The results of the study are listed below.

1 The benefits of IC as perceived by the users are: prevention of accidents (91%); smoke removal (84%); clean kitchen (84%), fuel saving (65%); cleaner vessels (60%); and time saving (50%). However, about 10% of the users felt that there was no fuel saving and about 21% of the users felt there was higher fuel consumption. In spite of the reasons, listed above the households were using ICs mainly because of the smoke removal feature

2 Thermal efficiencies boiling tests were conducted in sample households to find out the thermal efficiencies which indicated efficiencies ranging from 16 to 19% for ICs and 7 8 to 11.6% for the TCs.

3. Daily energy consumption: the daily adult energy consumption was calculated based on kitchen performance test. The energy consumption varied from 31 to 116 MJ and 27 to 109 MJ for the traditional and ICs, respectively.

The best way to disseminate ICs is to increase the awareness about them and to train local people in their construction In the hilly villages, it is possible to motivate households to partly pay for improved stoves They can also be persuaded to use the improved stoves and the programme can reduce the biomass consumption of the households as well as villages The energy saving by ICs as compared to TCs was 10% in the study villages

Acknowledgements

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References

Joshi V, Saksena S, Prasad R, Bose R, Zutsi P, Sharma A 1991 Study of energy use and environmental effects in the Garhwal region of the central Himalaya and an action plan for mitigation. Submitted to the Ministry of Environment and Forests New Delhi Tata Energy Research Institute.

Joshi V, Sharma A, Prasad R, Saksena S, Gupta S, Singh B. 1994. Study of energy and non-energy uses of biomass resources and development of biomass management plans for selected villages in the Irgad micro-watershed in Pauri Garhwal Submitted to Department of Science and Technology. New Delhi: Tata Energy Research Institute

Prasad R, Sharma A, Joshi V 1994. Stress on woody biomass resources due to energy needs in Pauri Garhwal district of central Himalayan region Paper presented at the *National Conference on Ecology and Environment* Garhwal University Campus, Pauri Garhwal, Uttar Pradesh.

Prasad R, Joshi V. 1992. Dissemination of improved cookstove in hill area – a case study New Delhi: Consortium on Rural Technology.

VITA. 1985. Testing the efficiency of wood-burning cookstoves. Prepared from the *Proceedings of a Meeting of Experts* convened in December 1982 by the Volunteers in Technical Assistance. Virginia. Volunteers in Technical Assistance

TRADITIONAL COOKSTOVE – *HARA*: EFFICIENCY, EMISSIONS, AND SCOPE FOR MODIFICATIONS

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Background

Hara is a traditionally designed special earthen pot for burning sun-dried cattle dungcakes. It is mainly used for slow heating of milk over three to four hours so that, without boiling the milk, the cream separates as a thick layer at the surface. It is also used for cooking fodder for livestock. *Hara* is widely used in the villages of Haryana, Uttar Pradesh, Punjab, and some parts of rural Rajasthan, Bihar, and Madhya Pradesh.

Bioresidues, of which agricultural residues form a major component, can be effectively utilized to reduce the consumption of both wood-fuel and dungcakes in the villages by briquetting them. Previously, these residues were often left to recycle in the agricultural fields adding to the soil fertility. However, with the ever-increasing scarcity of fuelwood, these are now collected and burnt as fuel. A major disadvantage in using agricultural residues as a fuel is their low bulk density. Since they have a relatively small particle size (e.g., straw), they burn too fast, and it is difficult to obtain a satisfactory level of heat for cooking. They have low calorific values, either because of moisture or their chemical composition, which make them slow to light. Moreover, on burning, the smoke emission levels are also quite high. Besides, the transport and storage of agricultural residues is also expensive (McChesney 1985). In India, there is a large supply of crop residues, nearly 390 million tonnes (mt) per year (TIFAC 1992). The all India utilization pattern of crop residues gives 35.28% as domestic fuel, 20.30% as cattle feed, and 18.65% for paper and board production. Taking only domestic fuel usage, it still constitutes an enormous source for briquetting. The percentage share of the *Hara* using states in the total production of crop

residues, namely, Bihar (6.7%), Haryana (4.4%), Madhya Pradesh (7.5%), Punjab (10.4%), Rajasthan (4.1%), and Uttar Pradesh (16%), also indicates a large supply of crop residues that can be utilized for briquetting (TIFAC 1992).

The other major biofuel used for cooking in rural areas is animal dung. The net dung available in the country was 433 mt in 1994/95 (TERI 1995). The utilization rate of dung in an area, however, depends upon the climate and fuelwood availability. A compilation of survey data of 638 villages shows that the main fuel used for cooking was firewood, followed by dungcakes, with the average per capita consumption of 1.2 kg/day and 0 4 kg/day, respectively (REDB 1992). According to the National Council of Applied Economic Research (NCAER) estimates, *Hara*-using states are the highest consumers of dungcakes. In fact, the per capita daily consumption of dungcakes as fuel is higher than firewood for a majority of these states (REDB 1992)

The traditional use of dung involves collection of animal wastes, as a supplement to, or as a replacement of, other traditional fuels, typically fuelwood and crop residues. The consequent impact on agriculture productivity is seen as a diversion of natural fertilizers from agricultural to energy end-uses. Dung is traditionally left in the agricultural fields and serves as organic manure. Burning it as fuel in *Hara* thus has an opportunity cost in terms of nutrient loss to agricultural fields. The subsequent impact on food supply is closely linked to the associated nutritional and health impacts. An offshoot of the above is the impact on animal fodder supplies and carrying capacity of livestock, including production from milk-yielding animals (Ramani, Reddy, Islam 1995)

The use of dungcakes as fuel in *Hara* is highly inefficient, causing several environmental and health related problems associated with indoor air pollution (CO, total suspended particulates, NO_x, HCHO), particularly for women and children, and impacts on the global carbon balance. Processing/preparing of dungcakes involves certain potential health hazards for women, such as fecal, oral, enteric, and skin infections. On the other hand, inefficient combustion of biofuels produces smoke which can cause a variety of health-related problems such as conjunctivitis, acute respiratory infections, upper respiratory irritation, etc., while smoke inhalation could lead to chronic bronchitis and even lung cancer. Continuous attention to the fire could also cause burns and cataract.

These problems, however, can be largely overcome by compacting the loose biomass (compression ratio of approximately 7:1) to form biomass briquettes. The advantage of briquetting is that wastes and residues can be upgraded to become wood (or charcoal) substitutes with advantages of easier transport, storage, and usage. Another argument in favour of briquetting biomass is that though more efficient stoves/devices could reduce residue consumption, these, however, would have to be designed for specific residues and operated properly to achieve the savings and the benefits aspired for. With the low rate of dissemination of stoves and time required for designing or modifying the traditional devices, an immediate impact on residue consumption is difficult to accomplish. Hence, upgrading the residues to the level of wood-fuel substitutes by means of a briquetting process and using these in the traditional devices such as *Hara*, seems, therefore, to be a more appropriate potential solution.

Minimization of the opportunity costs involved in the loss of soil nutrients as a result of the traditional usage of dung can also be greatly achieved. It would also reduce the

drudgery of women, who have to spend a lot of time in the collection and preparation of dungcakes. The collection, preparation, and storage of crop residues is also the work of women. The gathering and collection of fuelwood involves potential health hazards for both women and children, including allergic reactions, fungus infections, severe fatigue, muscular and back pain, arthritis, etc. (Batliwala 1995). There is, therefore, a need for more efficient use of biofuels in the villages.

The study

A micro level study on assessing the potential use of briquettes as an alternative fuel in *Hara* was carried out in village Garhi Natthe Khan located in Gurgaon district of Haryana. It was seen as an initial attempt to determine the efficiency and emissions from the traditional *Hara* by conducting field experiments with both biomass briquettes and dungcakes so as to assess the technical feasibility of initiating a fuel switch at the local level. Also, it was attempted to try the 'demonstration effect' by which the benefits of the new fuel will spread within the village and even the surrounding villages, through word of mouth. The users' perception of benefits/drawbacks of the alternative fuel and local usage of *Hara* was also studied to assess the socio-cultural feasibility of the attempt.

Garhi Natthe Khan is approximately 65 km from Delhi. The total human and livestock population in the village in 1995 was 730 and 232 respectively. All the households in the village use *Hara* for simmering milk and for cooking fodder. Milk simmering is one of the main energy-consuming activities in the households. Dungcakes are the main fuel used in *Hara*. A sample survey of 14 households in the village indicated an average daily consumption of 23 kg of dungcakes per household in both *chulhas* and *Haras*. Since dungcakes are used only for lighting the fire in *chulhas*, a major quantity of dungcakes are burnt in the *Hara* itself. The total cowdung consumption in these stoves would be about 165 tonnes per year. The women prepare dungcakes every day which involves collecting dung, preparing cakes, sun drying, and storing them, spending on an average one to two hours per day depending on how much dung a woman has access to, and the amount of cooking fuel that is required by the household. On the other hand, crop residues are solely burnt as fuel in *chulhas*, the average daily consumption of crop residues being 14 kg per household. The crop residues mainly used as fuel in the village are mustard stalks. While dung is available from within the village free of cost, crop residues are obtained either from personal agriculture produce or as return from agricultural labour. Very few households purchase crop residues, which serve primarily to fulfil fodder requirements.

Two design variations of the *Hara* are used in this village: portable and fixed. The portable *Hara* is an unfired earthen pot made either in the shape of a hemisphere or a closed bottom cylinder. On the other hand, the fixed *Hara* is in the form of a pit, dug in the earth with about 1.5 ft diameter and the same depth. The pit is enclosed by brick walls on three sides and with a red stone slab as roof. The front side of the *Hara* might be open or have a wooden plank as a door Ventilation is provided in the form of a large number of small perforations in the walls created by the staggered arrangement of the bricks These are made by the households themselves, and are mostly located outside the house, generally in

the courtyard. The usage of the *Hara* varies with the requirements of the households or the number of livestock, in case of fodder preparation.

Experiment methodology

A series of cooking tests were conducted on traditional *Haras* in the field. This was done in order to determine any efficiency improvements and reduction in emissions of this traditional device while using biomass briquettes in comparison to dungcakes. The device, task and fuel combinations for experiments are given in Table 1.

Procedure for conducting the experiments

- The prevailing weather conditions and ambient temperatures were recorded.
- The device location and position of doors and windows (if any) were noted down.
- The cook was asked to set aside the amount of fuel to be used, which was then weighed.
- The weight of the dry fodder and water, or milk in the case of milk simmering experiments, were measured separately. The quantity of fodder or milk was set aside by the cook.
- The time when the fire was lit and the time when the pot was put down were noted.
- The temperature of the fodder preparation/milk for 10 and 5 minute intervals, respectively, was measured till the cook removed the pot.
- The time when the pot was removed was recorded
- Any additional fuel, added or removed, was weighed and noted.
- The major observations (only qualitative) were noted down, including smoke produced, change in the fuel burning, cook's activities, removal of lid, stirring of fodder, difficulties experienced in catching of fire, irritation in the throat, watering of the eyes, poor visibility, etc.
- The final weight of the remaining fuel, both charcoal and ash, was measured.

In the case of char briquettes, the cook was asked to remove some briquettes when the milk raised. The time and quantity of fuel removed was noted down. This was done to prevent

TABLE 1
Task and fuel combinations used in the *Hara* for the experiments

Task	Fuel
Milk simmering	Dungcakes
Milk simmering	Char briquettes
Milk simmering	Green mustard straw briquettes
Fodder cooking	Dungcakes
Fodder cooking	Char briquettes
Fodder cooking	Green mustard straw briquettes

the milk from overflowing. The temperature measurements were noted till the cook decided to remove the pot from the *Hara*.

Instruments used

1. Thermometer for temperature measurement
2. Spring balance for weight measurement
3. Ordinary watch for time

Results

From the recorded values, fuel requirements for each task and duration of the task were calculated

Quantity of fuel consumed

The quantity of dungcakes consumed for the same task in the *Hara* was nearly 2.5 times greater than (by weight) either char or mustard straw briquettes (Table 2). Hence, the same task can be performed with less quantity of fuel, leading to savings in fuel consumption.

Time taken to perform the task

The same task can be performed in nearly half the time when using briquettes (Table 2). Hence, the same briquettes can be utilized for other tasks including cooking in *chulhas* or space heating.

Participant observation of the experiment procedure showed decrease in smoke produced when the briquettes were burned in comparison to dungcakes and no attention to the task was required by the user. The results have been given in Table 2

The quantity of milk simmered in the milk-simmering experiments with all the three fuels was 6 kg, while the quantity of fodder cooked was 1.5 kg of dry fodder with 6 litres of water.

TABLE 2
Fuel requirement and duration of task

Fuel	Quantity of fuel consumed for specific task (kg)		Time duration of task (hours)	
	Fodder cooking	Milk simmering	Fodder cooking	Milk simmering
Char briquettes	1 20	1.05	1 10	3.5
Green mustard straw briquettes	1.00	1.25	1 00	3.5
Dungcakes	2 75	2 75	1 40	5.5

Temperature profile

The briquettes as a fuel were able to keep a constant high temperature, ideal for milk simmering, for a considerably longer duration as compared to dungcakes (Figure 1). Also, the temperature of 100 °C was achieved only after 70 minutes in case of char briquettes and 90 minutes in case of green mustard straw briquettes, while for dungcakes it was not achieved even after 120 minutes (Figure 2). It is important to mention that the users were satisfied with the quality of the end product, especially with regard to milk simmering. For fodder preparation, on the other hand, the maximum temperature was achieved only after 50 minutes and the cook, satisfied with the product, finished the task in the next 10 minutes However, while using dungcakes only after 120 minutes a satisfactory level of heat was obtained (Figure 2).

Users' views on performance of briquettes in traditional *Hara*

Briquettes as a fuel was unheard of in Garhi Natthe Khan before. However, after a series of discussions for familiarizing the households with this new fuel has been conducted, the women showed keen interest in using them. Two kinds of briquettes were distributed in sample households on a pilot scale to assess the user response This micro-level approach was adopted to ensure the sustainability of the intervention if attempted on a large scale. The briquettes distributed were char briquettes (11 households) and green mustard straw briquettes (4 households). The latter was distributed because mustard straw is the locally available raw material. If a village-level independent briquetting system had to be designed

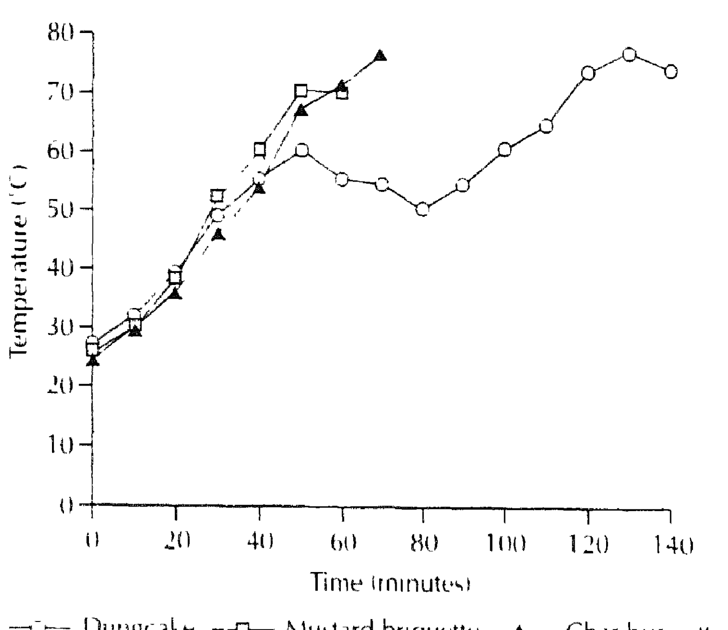


Figure 1. Temperature profile of milk simmering with different fuels

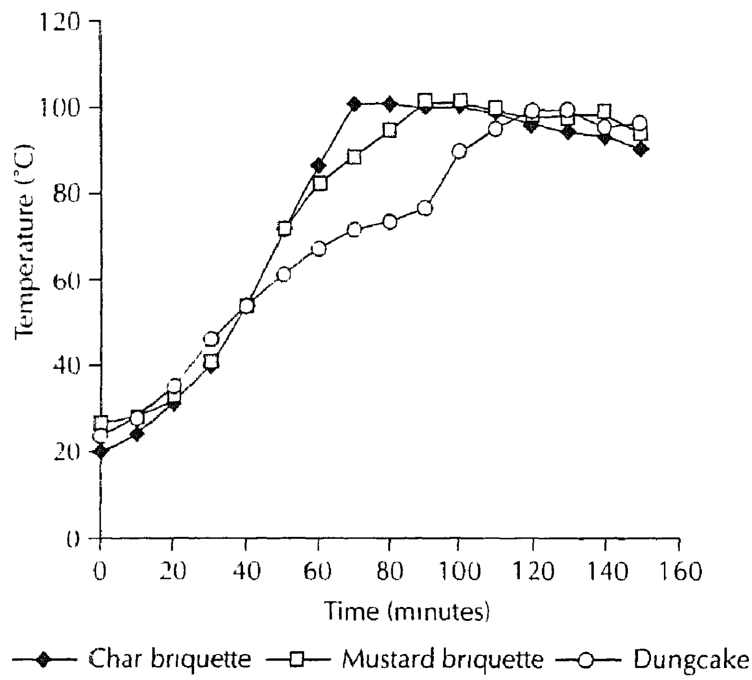


Figure 2. Temperature profile for fodder preparation with different fuels

and consequently implemented, the focus would have to be predominantly on the local materials, and on a simpler process of production to start with. Demonstrations were also made to the households on the use of briquettes in the *Hara* and they were familiarized with the benefits.

Views and perceptions of the users, principally the women, were collected in a series of individual and group interviews. The women were clearly able to articulate the benefits and drawbacks of the use of briquettes in the *Hara*. The women of these households had used the briquettes in both the *Hara* and the *chulha* and were very satisfied with their performance. In the *chulha*, the briquettes were used in combination with fuelwood and dungcakes, thereby reducing the quantity of fuelwood otherwise consumed

The users informed that the briquettes burned for a much longer time than animal dungcakes. A particular household reported that the briquettes were burned at around 2 30 p m but, long after that at around 8.30 p.m , the household took the same briquettes, still burning in the *Hara*, to fill the *chilam*[1]. Also, the heat produced from briquettes was more. All the users said that the number of briquettes used once in the *Hara* was less than the number of dungcakes generally used. While six briquettes were sufficient on each occasion, in case of animal dungcakes about eight to nine dungcakes were utilized each time With the briquettes, the household could easily cook fodder twice in one day while, the dung available is not sufficient to do the same task with the above frequency. Further, they found it easier to burn briquettes as compared to dungcakes. Very little effort was required to ignite briquettes which catches fire very quickly Upon burning, the briquettes produced considerably less smoke than dungcakes. Though it was difficult for

[1] The *chilam* is a traditional smoking pipe

the users to visualize the harmful effects of the smoke produced in absolute medical terms, they did perceive smoke to be a problem, primarily as an irritant. Ideally, while using the *Hara* the smoke produced on burning dungcakes is not a major problem because the task of either fodder cooking or simmering milk does not require the continuous attention of the user However, in this particular case, as the users had burned briquettes in *chulhas* also, they reported the decrease in smoke as beneficial.

The women also described briquettes as a time-saving fuel. For using animal dungcakes they first have to prepare them, dry them, collect them from the *bitola*[2], crush them, and then use them. All this can be avoided when using briquettes. Also, the task did not require any personal attention in the form of tending to the fire or the arrangement of the briquettes once they were ignited This gave them more time to attend to other home tasks

The benefits of briquettes in the *Hara*, as perceived by the users, in the order of priority are listed below.

1. Produces more heat.
2. Burns for a longer time
3. Saves time.
4. A lesser quantity required for the same task
5. Ignites quickly
6. Produces less smoke
7. Requires no attention

It is important to mention here that the above features of briquette were noted more in char briquettes than in green mustard straw briquettes by a majority of the users.

One of the main issues in confirming the acceptability of the fuel was the willingness of the people to purchase briquettes The target respondents in this case were the men who take most of the monetary decisions The introduction of the new fuel was thus projected as an income-generating activity for unemployed youth This was seen as an initiative to fulfil the twin objectives of augmenting the supply of fuel for the households, and setting up an independent, self-sustaining, income-generating activity at the village level.

An appropriate system of manufacturing and marketing briquettes at the local level has thus been designed with the aid of the villagers.

Conclusions

The use of briquettes in the *Hara* is an attractive option that needs to be explored The present study has been confined to exploring the possibility of using briquettes in the *Hara*, and to examining its technical and socio-economic feasibility at a micro level It is, thus, to be seen as an initial step in the direction. However, it opens several avenues for

[2]The *bitola* is a stack of dried animal dungcakes, plastered with a mixture of dung and mud and covered with straw

further research. The option of use of briquettes in *chulhas* could be further explored. Further, design improvements in *Haras* and *chulhas* for a more effective utilization of briquettes could be another area where further research could be done. The reasons for advocating the need for such an effort are several.

1. It would result in the efficient use of both crop residues and dung.
2. It would permit the rediversion of dung and crop residues as natural fertilizers in agricultural fields, thereby enhancing crop productivity.
3. It would bring with it numerous health benefits for women.
4. It would help in reducing the environmental impacts due to inefficient burning of biofuels.
5. It would lessen the burden of work and reduce the drudgery of fuel collection and preparation for women.

It is too early to say something definite with regard to stove design improvements. However, efficient use of biofuels by introducing alternative fuels such as biomass briquettes and educating the rural population on the correct usage of the new fuel could be seen as promising start.

References

Batliwala S 1995. *Bearing the brunt of labour. The Hindu Survey of Environment* Madras: M/s Kasturi & Sons Ltd.

McChesney I 1985. Briquetting wastes and residues for fuel *Appropriate Technology* **12**(2) 23–25.

Ramani K V, Reddy A K N, Islam M N (eds). 1995 Rural Energy Planning. a Government Enabled Market-based Approach Kuala Lumpur, Malaysia: Asia & Pacific Development Centre

REDB. 1992. *Rural Energy Database* Report submitted to the Ministry of Non-conventional Energy Sources. New Delhi: Tata Energy Research Institute

TERI. 1995 *TERI Energy Data Directory and Yearbook (TEDDY) 1994–95*. New Delhi. Tata Energy Research Institute

TIFAC 1992 Biomass generation and utilisation New Delhi: Technology Information, Forecasting and Assessment Council, Department of Science and Technology.

Section 5

Biogas technology

BIOGAS PROGRAMME IN NEPAL

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Introduction

Nepal is an agricultural country with more than 90% of the population engaged in agriculture and related activities. With the reduction of forest cover in the fragile ecology, problems of soil erosion, landslides, and floods have become more common than in the past. Together with the growing population, there is an ever-increasing pressure on the remaining forest and cultivated land.

The total energy demand of the country is estimated at about 252 million gigajoules. 95% of this is used in the domestic sector, mainly for cooking. The bulk of this energy demand is met by firewood (80%), agricultural residues (10%), dungcakes (9%), petroleum products (0.5%), and electricity (0 5%). Between 1980 and 1992, the burning of agricultural waste and dung cakes has increased 15-fold. Substituting traditional household energy with some alternatives was of pressing need. Of all other sources of alternative energy tried out in the past, biogas technology has proved to be the most preferred technology, as it is economically viable, socially acceptable, technically feasible, and sustainable and manageable in the context of Nepal.

Biogas

Methanation is a process through which biogas is produced by anaerobic decomposition of organic materials by the action of methanogenic bacteria. This gas is mainly composed of methane (50–60%) and carbon dioxide (30–40%), with some hydrogen and traces of

nitrogen, ammonia, and hydrogen sulphide. The proportion of methane and other gases varies according to the nature of organic materials used. Theoretically, all biodegradable materials can be used to generate methane through anaerobic decomposition. However, in practice, mainly animal dung (especially that of cow and buffalo) is used as raw material for feeding biodigesters in Nepal.

In Nepal, biogas is used mainly for domestic cooking, and, to some extent, for lighting, to replace firewood and kerosene. The industrial application of biogas to run dual fuel engines, refrigerators, and to generate electricity has been attempted on a limited scale. Similarly, some work has been done on the production of biogas from biodegradable materials other than animal wastes, for example, agro-industrial and municipal wastes. One of the pressing needs of the country is to promote the concept and to produce commercially viable bio-energy and organic fertilizers to enhance crop production.

Brief history of biogas development in Nepal

Technology

The first biogas plant in Nepal was introduced in 1955 by Father B R Saubolle (late), made out of a used oil drum, at St Xavier's School, Kathmandu. Till early 70s, the technology remained a subject of personal interest for some individuals, and a few plants were constructed in Kathmandu merely out of personal curiosity

The world energy crisis of 1973 created a global interest in developing alternative energy technologies. In Nepal, this led to the formation of an Energy Research and Development Group (ERDG) in 1975, at the Tribhuvan University A Biogas Development Committee (BDC) was also formed as a part of ERDG. These initiatives taken by an academic institution were instrumental in attracting the interest of government authorities to the relevance of biogas technology in the overall development context of Nepal.

The Ministry of Agriculture (MoA) observed the fiscal year 1975/76 as the 'Agriculture Year'. Biogas was included as a special programme, particularly for controlling deforestation and preventing burning of cowdung, which otherwise could be used as an organic fertilizer to improve soil fertility for increased crop production Interest-free loans were given to families for the construction of biogas plants. These organized efforts led to the construction of the first 250 family-size plants in 1975/76, under the supervision of the Department of Agriculture (DoA). All these plants were of floating drum type (Figure 1) designed by the Khadi and Village Industry Commission (KVIC) of India. However, the national attention and momentum gained in spreading this technology subsided drastically after the 'Agriculture Year' was over

In 1976, a few technicians were trained under the US Agency for International Development (USAID)/Nepal-supported 'Studies of Energy Needs into the Food System' project In 1977, the Gobar Gas and Agriculture Equipment Development Company Pvt. Ltd (GGC) was set up in collaboration with: (i) the Development Consulting Services of the United Mission to Nepal (UMN), (ii) the Agriculture Development Bank of Nepal (ADB/N), and (iii) the Fuel Corporation of Nepal (FCN). Thus, GGC as a private company became the first organization to be fully responsible for overseeing the development

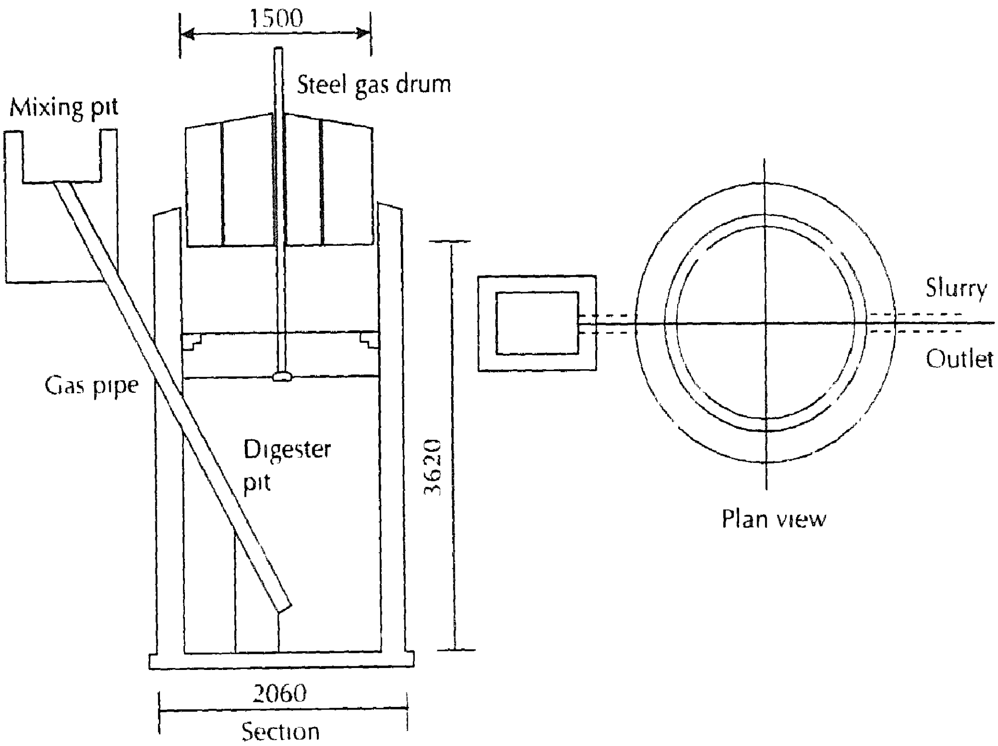
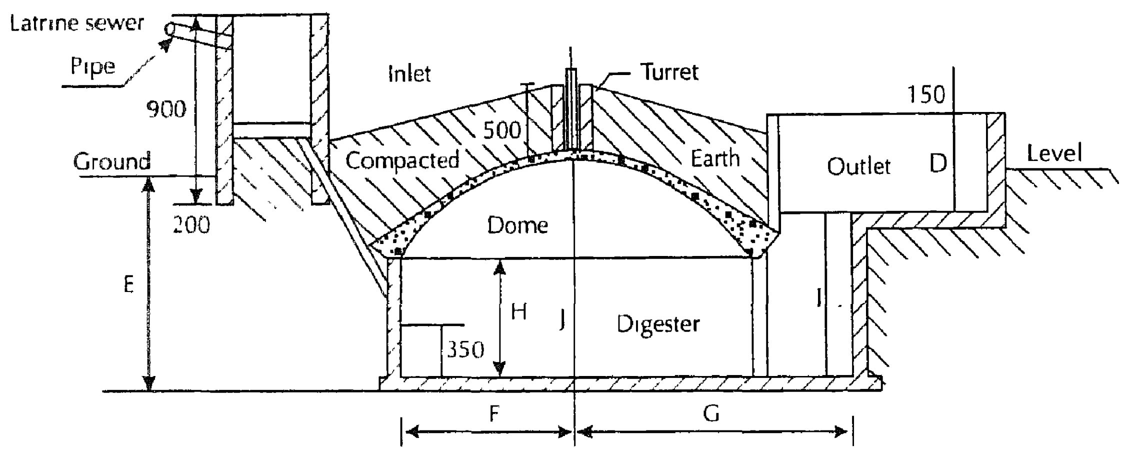


Figure 1. The KVIC floating gas holder system

of biogas technology in the country (Karki, Dixit 1984). And, for 17 years since then, it remained the only organization responsible for the promotion of technology in the country. By 1978, the country had a total of 708 plants; all of which were of the floating drum KVIC type.

The difficulty in transporting a heavy and big metal drum of the KVIC design became a serious limiting factor for its wider use, particularly in remote areas. As an alternative, a drumless design originally used in China was modified, and the first drumless plant was constructed as an experiment in 1978 by the DoA. This design became popular soon because of its lower initial investment cost compared to that of KVIC model. Consequently, the construction of KVIC type plants was stopped by 1987 and all plants are now constructed of drumless design with concrete dome (Figure 2). The design parameters for plants of different sizes are approved by the Biogas Support Programme (BSP) Subsidies are not provided for plants that do not follow these standard parameters. This approach has been taken after an evaluation revealed that more than 90% plants with these parameters were successful, which is a very high rate of success compared to that of other countries However, the limiting nature of this approach is being cautiously modified to allow the promotion of other model plants such as the *Deenbandhu* model (Figure 3)

The biogas plants constructed by various companies are of different sizes: 4, 6, 8, 10, 15, and 20 m^3, out of which the 8 and 10 m^3 sizes are the most common. The average size of biogas plants constructed each year has been decreasing from about 10 m^3 in 1990 to 9.25 m^3 in 1995. Programmes are being launched to bring this size further down to about 8 m^3.



Component	Plant capacity (m³)					
	4	6	8	10	15	20
A	1400	1500	1700	1800	2480	2640
B	1200	1200	1300	1250	1250	1760
C	1350	1510	1700	1830	2050	2330
D	500	600	650	680	840	860
E	1540	1550	1720	1680	1800	2030
F	1020	1220	1350	1540	1750	1990
G	1850	2080	2210	2400	2610	2880
H	860	920	1050	940	1150	1150
I	1120	1160	1270	1240	1320	1370
J	1510	1600	1750	1710	1930	2030

All dimensions are in mm

Figure 2. GGC concrete model biogas plant

Government policies

It was in 1975/76 that the Government of Nepal first took the initiative for the promotion of the biogas technology. In that year, the government provided interest-free loans for families to install biogas plants In the following year, the incentive was changed to a preferential loan at six per cent interest rate channelized through ADB/N. In 1982/83, a subsidy of NRs 5500 was provided to each plant constructed in some specified districts only. In the Seventh Five Year Plan Period (1985–90), the government decided to provide a subsidy of 25% on the construction cost and 50% on the interest of loan from ADB/N. But these policy provisions were removed in 1990/91 in favour of the general policy to do away with credit subsidies These frequent policy changes and their inconsistency had been the main bottleneck in the biogas programme. Since 1992, the policy has been to provide a subsidy amount of NRs 7000 for each family-size plant constructed with the given design parameters An additional NRs 3000 is provided as transport subsidy for hilly districts. These subsidies are provided irrespective of the plant size

The plan for construction of biogas plants was first included in the Seventh Five Year Plan (1985–90) with a target to construct 4000 plants during the project period. It was

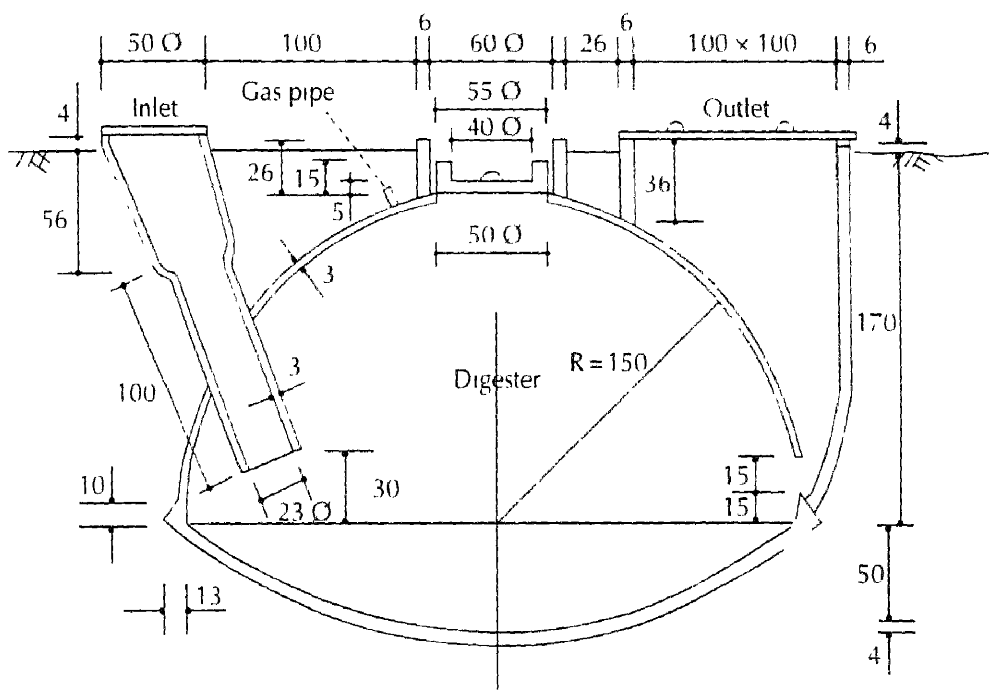


Figure 3. Brick-type *Deenbandhu* model biogas plant

considered an ambitious plan but was easily achieved. Encouraged by this achievement, the Eighth Five Year Plan (1992–97) has set a target of constructing 30 000 plants, which is judged to be fully achievable before the end of the planned period.

The three important factors that contributed to the rapid increase in number of biogas plants are: (i) the implementation of BSP with financial support from the Netherlands Development Corporation (SNV), (ii) the government policy on privatization that prompted entrepreneurs to form new biogas companies (other than GGC) – the country now has 22 such companies; and (iii) easier flow of subsidies through banks. New biogas companies are registered with the government under cottage industries and they vary widely in their technical capabilities.

It is interesting to note that the government has to fully rely on the private sector to meet the target it has set. However, efforts are being made to establish a National Biogas Centre (NBC) as a government entity to oversee the development and management of the biogas sector. The Ministry of Forest and Soil Conservation is now designated as the contact or liaison ministry for this purpose till the NBC is actually established

Organizations involved in the biogas sector

Government agencies

In the initial phase, especially during the Agriculture Year in 1975/76, the MoA was actively involved in the promotion of biogas technology. To some extent, the Energy Planning Division of the Water and Energy Commission Secretariat (WECS) has also been

involved, especially in studies for monitoring, evaluation, and training. However, the biogas sector has largely remained in the hands of private sector and the ADB/N, which is a semi-government national institute for rural credit. However, a proposal to establish a government body to oversee the biogas sector is under active consideration.

ADB/N and other commercial banks

ADB/N was established in 1968 and provides rural credit services through over 700 field offices strategically located to reach even the remote areas of the country From 1974/75 to 1995, it has been the only agency to administer loans and government subsidies for biogas construction. Though a financial institution, it has also been involved in promotional activities such as information campaign and training in the biogas sector

With the growing demand and need to spread the technology widely, other commercial banks have also started financing the construction of biogas plants. However, institutional credit facilities of these banks are limited to financing the individual plants only.

Donors, NGOs, and consultancy firms

Various donors such as SNV, United Nations International Children Education Fund, Save the Children, USA, Plan International, and the Food and Agriculture Organization (FAO) are involved in the promotion of biogas programme in Nepal. Their involvement has been mainly in providing financial support and the necessary technical assistance.

The number of non-government organizations and consultancy firms involved in biogas is also increasing Some of the prominent companies are: Consolidated Management Services Nepal, New Era, and East Consult The activities of these companies are limited to conducting socio-economic research, programme evaluation, and training

BSP

The Biogas Support Programme (BSP) was started in 1992 as a collaboration of GGC, ADB/N, and SNV. The short-term objectives of the BSP are: (i) to support the construction of 20 000 plants (7000 plants in the first phase, i e., 1992 to July 1994 and 13 000 in the second phase, i.e., July 1994 to 1997) by providing subsidies through ADB/N; (ii) to make biogas more attractive to smaller farmers in the hills; and (iii) to formulate well-considered recommendations for promoting the private sector participation in the biogas sector. Current activities of BSP include: recognition of biogas companies, widening access to credit for biogas, providing subsidies to biogas plants, quality control in the construction of biogas plants, research and standardization, training and extension, monitoring and evaluation, and support to policy and planning of the sector. At present, BSP is being implemented collaboratively by SNV, ADB/N, and recognized biogas companies.

FAO

FAO has been supporting the promotion of biogas technology in the developing countries since many years. Recently, a project titled 'Support for the Development of a National Biogas Programme' has been implemented under the Technical Cooperation Programme of FAO The activities include mainly training of masons and biogas users and utilization of digested slurry as fertilizer.

GGC and other private biogas companies

GGC has been the only organized body responsible for the overall development and management of the biogas sector for 17 years (1977 to 1994). Since 1994, more than 22 other companies have come up to provide construction services to meet the ever-increasing demand for the installation of biogas plants.

Potential of biogas in Nepal

As pointed out earlier, biogas technology in Nepal is generally understood as a means to produce cooking and lighting fuel by feeding a digester primarily with cattle dung. With this limited view on the technology, the national potential is calculated on the basis of dung from cattle population that could be available to feed biodigesters in different parts of the country.

The total population of cattle and buffaloes in Nepal is estimated to be 9.3 million in 1990/91; this number shows an increasing trend. These animals produce about 37.4 mt of dung every year. Assuming that only 75% of the dung can be collected, about 28.1 mt will be available for use in biogas plants (van Nes 1992). With these figures, Nepal has the potential to produce 673 million m^3 biogas annually which is equivalent to 4038 GWh in terms of hydro power, or has the potential to substitute 390 million litres of kerosene costing about NRs 3510 million or 3.7 million tonnes of firewood. In terms of average family-size plants of 10 m^3, Nepal has a potential of establishing 1.3 million biogas plants.

Based on the annual temperature, only 56 of the 75 districts of Nepal have been found suitable for proper operation of biogas plants. The national average size of the potential biogas plants is 6 to 8 m^3 based on the number of animals raised by an average farming family. The biogas demand for cooking and lighting for the 'potential biogas households', i.e., households that have enough cattle to have a biogas plant, is 878 m^3 per year which is 77% of the production potential.

Performance review of the biogas sector

Technical

Nepal has adopted the 'single design and multi-private sector institutions' approach for the promotion of biogas technology in the country. The design in use was developed about a decade ago and has had good results both in the hills and in the plains as more than 90% of the constructed plants were found to be functional. As stated earlier, this rate of success is very high compared to world standards. However, cautious steps are being taken to move towards the 'multi-design and multi-institution' approach.

The most common problems related to biogas plants, in decreasing order of their magnitude, include: (i) gas production lower than the plant capacity; (ii) gas leaks from the dome; (iii) slurry in gas pipes; (iv) blockage in inlet; (v) leakage from the gas valve; and (vi) poor quality construction. Other general problems that the sector suffers from are listed below:

- Because of the low investment capacity of farmers, the present level of government subsidy is considered insufficient even though it meets more than 50% of the initial investment costs.
- Inadequate post-construction services and user training.
- A general trend of decreasing number of livestock in the households after the construction of plants.
- With growing scarcity of water supply in urban areas, the water available to feed the plants is also declining.
- There are high variations in the materials used and the price charged by biogas companies from the beneficiaries.
- There is a tendency to construct an oversized plant because the technicians get more construction fee and farmers can get more loan from the bank for bigger plants.

Distribution

Out of 75 districts of the country, 19 districts have the potential to establish less than 1000 plants with the climate and population being the main limiting factors. The concentration of biogas plants is higher in the urban areas and in areas with easy access by road. This tendency is attributed to the increasing scarcity of household fuel in these areas and easy access for service institutions such as banks and biogas companies Increasing scarcity and price of firewood, easy access to credit facilities and technical services, and growing awareness have been the three main factors to motivate a farmer for installing a biogas plant. Of the total potential of 1.3 million plants, 62% is in the plains, 37% in the hills, and 1% in the mountains.

Economics

The average prices of the popular-size biogas plants, i.e., 8 and 10 m^3, in 1996 prices are NRs 22 000 and 25 000, respectively. The owner is eligible to receive a subsidy of NRs 7000 in the Terai and NRs 10 000 in the hills for each plant constructed irrespective of the sizes of the plants Loans can be obtained from ADB/N and other commercial banks which are payable in seven years at the current interest rate of 16% per annum. The subsidy amount is sufficient to meet more than 50% of the construction costs. Depending on the access to roads and the availability of construction materials near the construction site, the construction cost could be brought down by as much as 40% (Karki, Gautam, Joshi 1993).

For economic calculations of the plant, the price of kerosene is taken for comparison. A 10 m^3 plant, under optimum working conditions, can produce 3 m^3 of gas (0 3 m^3/m^3 digester volume) per day Assuming that 1 m^3 of biogas is equivalent to 0.58 litres of kerosene and the price of kerosene being about NRs 9 per litre, a biogas plant gives a discounted (20 years) benefit of about NRs 5715 per year. This simple calculation does not consider other intangible benefits such as improvement in the environment and sanitation, improved health of housewives, etc.

Social performance

A majority of biogas users are medium and large farmers. As against the national average of 40% literacy rate, 80% of the biogas users are literate.

Women

A study carried out by Silwal, Pokharel (1995) with 100 users revealed that about three hours is saved per day by using biogas, which otherwise would have been spent in cooking, cleaning of pots, and collection and management of firewood. Use of biogas has shown a positive impact on health of housewives, specifically with respect to headaches, cough, and eye diseases. Even old asthma patients who could not cook before assumed the responsibility for family cooking after the installation of biogas plants.

Research

Research is one of the most neglected areas in the biogas sector in Nepal, both in terms of human and financial resources involved in it The main focus of promotional agencies and construction companies has been to increase the number of biodigesters in the country GGC has been promoting the same concrete dome design (based on Chinese technology) for the past 14 years. The *Deenbandhu* model, which replaces the concrete dome with a masonry one, has already been developed and successfully tried out in some parts of the country. The brick-typed *Deenbandhu* plant has been found to be at least 20% cheaper than that of GGC concrete plants (BNRM 1994). However, studies by BSP have not shown significant difference in prices between the GGC model and the *Deenbandhu* plants.

Research work on issues such as increasing gas production during winter has been a subject of much concern to the beneficiaries. The level of gas production during winter even decreases by about 25% in the *terai* and over 50% in the hills. Research on biogas production in cold conditions was undertaken in the Khumaltaar Agricultural Farm, Lalitpur, Nepal, some years ago by the Division of Soil Science and Agricultural Chemistry of the DoA. The results had indicated that the insulated plant produced about 93% more gas than the uninsulated one and heating the slurry prior to feeding the plant is not effective in increasing the gas production appreciably.

Even the limited research carried out so far has remained within the laboratory. Not much has been done to explore the possibility of using alternative feedstock. Although more than 30% of the family-size biogas plants in the country are attached to toilets, no systematic data are available on the effect of such practices. Reduction in construction cost is another area of research priority that has remained untouched. Use of local materials in biogas technology has not been given due consideration. Also, not much has been done to explore the possibility of producing biogas appliances locally.

Training and extension

By 1993, a total of 450 masons, 1705 users, and 115 construction supervisors were provided training. All these training programmes were conducted by GGC as it was the only specialized institution responsible for the promotion of biogas in the country (Karki, Gautam, Joshi 1993). In recent years, some of the newly established biogas companies have started providing training to their users with support from BSP especially for their respective biogas users. Since training and extension activities do not bring direct profit, private biogas companies have been less active in these important areas of the technological promotion. Furthermore, there are neither government organizations nor support available to carry out these activities. Considering this, BSP has come up with some ad hoc funds for supporting training programmes.

At present, besides GGC, the field staff of the DoA, ADB/N, biogas companies, and donor agencies like SNV are involved in motivating and educating farmers on the benefits of installing biogas plants. However, these extension activities are not properly coordinated, and, in most cases, the technicians are not adequately trained to undertake such work. Usually, the manure and sanitation value of biogas technologies are ignored in such extension efforts. Furthermore, only a limited number of women are involved in the extension activities (Leermakers, 1992).

Institutional strengthening

Institutional strengthening is yet another neglected area in the biogas sector. Other than the creation of GGC in 1977, there is no evidence of any programme or support for strengthening institutions and building up institutional capacity in the country. Though BSP was not designed to include the institutional strengthening component, it later took up the initiative to fill this gap. BSP supported studies to recommend suitable institutional arrangements and these suggestions are being actively considered by the government. The implementation of BSP recommendations would lead to the establishment of a national body to oversee all development programmes and processes of the biogas sector.

Major issues

One of the main issues concerning the wider application of the biogas technology has been the narrow view regarding the technology itself: that it is the technology that produces cooking fuel from cattle dung. The potential of the technology in terms of producing valuable organic fertilizers, treating urban wastes, generating commercial energy, and improving rural and urban sanitation is not a common knowledge in Nepal. As the technology has gained wide social acceptance and popularity as a family unit plant, it is high time that Nepal applies the technology to ameliorate many of the problems that the society is currently facing. The problem of urban waste management that has reached a critical level can be cited as an example. So far, all efforts are being directed to increase the number of household biogas units of a given design fuelled by provision of the subsidy at a level that the government may not be able to sustain on its own. Absence of government support and grant for activities such as research, training, and institutional strengthening has been the limiting factor for the sustained development of the sector and the wider application of the technology.

Biogas promotion is largely a private sector operation in Nepal. Private companies make profits out of their services rendered for the construction of a plant, and have very little incentive to carry out training programmes. This is because: (i) the technical competence of these companies in areas other than construction is limited; and (ii) the culture of paying for getting trained is yet to be developed among the biogas users. Moreover, there is no institutional framework to provide training in the biogas sector. At present, BSP fills this gap. These factors also limit the research aspect of the technology.

It is the lifestyles of the poorest of the poor sections of the population that adversely affect sustainable farming in the hills. No special provisions are being considered for the

socio-economically disadvantaged sections of the population particularly when their poverty-stricken lifestyles exert a negative impact on common property resources.

All biogas-related activities are run on a project basis and are guided by the availability of donor funding. They are yet to become a part of regular government programmes with government department or ministry to oversee them on a sustained basis.

References

BNRM 1994 Biogas and nature resource management. *Newsletter No 46*.
Karki A B, Dixit K 1984 *Biogas Fieldbook* Tripureshwar, Nepal Sahayogi Press
Karki A B, Gautam K M, Joshi S R 1993. *Future Structure of Biogas Sector in Nepal*
Leermakers M. 1992. Extension of Biogas in Nepal. Strategies for Implementation.

A BIOMASS-BASED STRATEGY FOR MEETING ENERGY NEEDS FOR RURAL DEVELOPMENT

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Introduction

The energy scenario in the world necessitates the development of alternative sources of energy for conversion and utilization. Biogas energy is one of them and the most promising for rural development.

About 987 million tonnes (mt) of cowdung is available in India. 25 kg of cowdung can produce about 1 m^3 of biogas which can substitute 2.44 kg of coal or 3.98 kWh of electricity. Biogas can achieve a thermal efficiency of 60% compared to the 11% that is achieved from cowdung cake burning. Other types of biomass, i.e., species of trees and plants, can also be used to generate biogas.

Biogas appears to be the most important energy resource in the agriculturally dominated rural sector. It has been estimated that agricultural products produce as much as five times more energy in the form of biogas than they do in the form of dietary energy. Biogas can be utilized in the following ways and could prove to be a boon in the development of rural sector.

- Cooking gas
- Brazing and welding
- Crop drying
- Electric power generation
- Biogas engines

Biogas as cooking gas

Biogas is a clean, cheap, and convenient cooking fuel. It contains CH_4, which is inflammable The setting up of biogas plants improves the sanitation around a household as well. Eye and lung diseases caused by kitchen smoke can be eliminated, and environmental conditions would improve as forest cover is protected by saving of fuelwood. The large-scale promotion of biogas plants also helps in generating employment in rural areas.

The size of a biogas plant depends upon the availability of cattle dung and the gas requirement of the beneficiary Generally, the dung from two or three cattle produces gas adequate to meet the cooking fuel requirements of a family consisting of three to four persons.

Keeping in view the availability of dung and requirement of gas, one can select the appropriate capacity of the plant as shown in Table 1.

Of late, the concept of the waste recycling and resource recovery system (WRRRS) has evolved from the ongoing programme of community, institutional, and night soil based biogas plants. The objective is to maximize the recycling of organic wastes available in villages and urban centres, resulting in the production of biogas and improvement in the environment.

Biogas for brazing and welding

Biogas produced by the anaerobic decomposition of human/animal/agricultural waste consists of 65–75% CH_4, 30–35% CO_2, and small traces of nitrogen, hydrogen sulphide (H_2S), and other gases. Its production rate is 0.089–0.33 m^3/kg of biomass fuel at a pressure of 5–9 cm of water column. The calorific value of the biogas is about 2024 kJ/m^3. Its calorific value can be enhanced 1 5–1.7 times by filteration of CO_2, H_2S, and water vapour from it.

Mixture of filtered biogas and oxygen can be used as a source for welding and brazing for non-ferrous metal sheets. Carbon dioxide from biogas can be filtered by passing it through lime water (calcium hydroxide)

TABLE 1
Capacity requirements

Capacity of plant (gas production in m^3/day)	Approximate number of cattle	Daily requirement of wet dung (kg)	Cooking gas available for number of persons
1	2–3	25	3–4
2	4–5	50	5–8
3	6–7	75	8–12
4	8–9	100	12–16
6	10–14	150	16–20
8	16–18	200	22-26
10	20–22	250	26-32

$CH_4 + CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O + CH_4$

Water vapour in biogas can be eliminated by passing it through calcium oxide.

$CH_4 + H_2O + CaO \rightarrow Ca(OH)_2 + 63$ kJ/gram.mole

This is an exothermic reaction, which enhances the heat content of the gas. H_2S can be removed by passing it through iron fillings.

The author has compared the tensile strength of the brazed joints on a universal testing machine for oxy-biogas brazing and conventional oxy-acetylene gas brazing. Results are given in Table 2.

These results indicate that the strength of oxy-biogas brazed joints is more than oxy-acetylene gas-brazed joints.

Biogas for crop drying

Biogas alone, or along with solar heat, can be used for crop drying. In the process, biogas is used to heat air, which, in turn, is used for crop drying.

The economics of different drying methods can be estimated as given below. (Swamy 1984):

$$P = \frac{K}{CET}$$

Where

P = performance index,
C = cost of drying in rupees,
E = energy consumed in kilocalories,
T = time of drying in hours, and
K = constant.

TABLE 2
Comparative strength of oxy-biogas and oxy-acetylene brazed joints

Sheet gauge	Strength of brazed joints (KN/m² x 10⁻²)					
	Oxy-biogas brazing			Oxy-acetylene brazing		
	MS[a]	Brass	Copper	MS	Brass	Copper
20	615	461	495	599	283	470
18	1318	833	432	699	714	399
16	1373	1516	186	873	988	72

[a] mild steel

For a higher performance index, parameters C, E, and T should be minimum. The performance index of different drying methods is given in Table 3. The table 3 shows that using biogas alone for drying (convective) shows the highest performance index.

Biogas for power generation

Biogas, along with diesel or by itself, can be used to run diesel engines. A Stirling engine has been developed to run on biogas. These engines can be used to drive the pump to lift water or to drive generators for electrical power generation. Biogas can be used for lighting purposes also.

Biomass-based cogeneration in sugar industries

India has the potential of producing 4654 mt of biomass annually. This biomass alone can be sufficient to meet the energy demands of rural areas to augment rural electrification. This, however, needs the development of efficient methods for the collection and utilization of this renewable source. Figure 1 shows the scheme for cogeneration.

At present, there are 419 sugar mills in India having a capacity of 10 mt of sugar per year. As per the Planning Commission estimates, by the end of this century, the number of mills may rise to 600 and will have a capacity of over 18 mt of sugar. (Sugandhi, Bagea 1993)

TABLE 3
Comparison of the crop-drying system

Method of drying	Performance index
Solar roof drying	1.8×10^9 K
Biogas (direct) drying	1.2×10^7 K
Biogas (indirect) drying	5.9×10^8 K
Biogas + solar drying	3.5×10^9 K
Floor sun drying	3.4×10^{10} K

Source Palaniswamy *et al.* (1994).

TABLE 4
Potential of biomass-based cogeneration

Year	Agrowastes available	Cogeneration potential (MW)	
		Existing	In future with biomass cogeneration
1995	5350	3354	7527
2000	8560	5367	9607

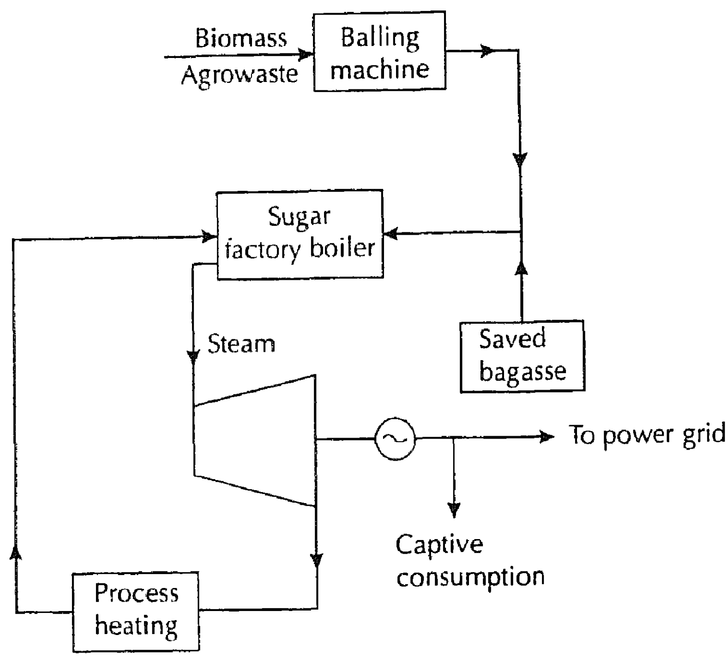


Figure 1. Biomass-based cogeneration

The estimated potential is shown in Table 4. At present in sugar industries, the by-product of bagasse is used to generate power for captive use. The plant and machinery is used only during the crushing season for about 160 days per year. If other agrowastes can be used in off-season for cogeneration, the plant can be utilized for the whole year

Conclusion

Biogas has enough potential to be used for various purposes and to meet the energy needs of rural areas. Biomass-based rural industries may be established to create employment opportunities for the rural youth.

References

Sugandhi R K, Bagea M. 1994 *Cogeneration of electric power in sugar industry* Pune Commissioner of Sugar.

Swamy P 1984 *Development of biogas burner accessory system for solar drying.* ME (Ag) thesis Coimbatore College of Agricultural Engineering, Tamil Nadu Agricultural University

Palaniswamy P T, Pugalendi S, Vijayaraghavan N C, Swaminadhan R K 1994 *Development and optimization of biogas burner–design parameters for use as an accessory unit in solar drying* Paper presented at the National Conference on Engineering in Rural Context, 24–28 November 1994

BIOGAS FROM LEAF BIOMASS: PROSPECTS AND PROBLEMS

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Introduction

The Indian programme on biogas has relied essentially on the use of cattle dung as the feedstock (DST 1981). The dependence on cattle dung poses two problems from the point of view of equitable development. The cattle dung in the villages is a skewed resource and is accessible only to the richer segments of rural society. Secondly, the dung is a limited resource and even when all the available dung is converted into biogas, only about 30% of the villages can cook using the gas. Therefore, if biogas has to have a widespread impact on all sections of the Indian society, there is a need to explore other feedstock for biogas production.

Brakel (1980) reported the possibility of obtaining biogas from a wide variety of agricultural wastes besides livestock wastes. However, these results represented laboratory experiments using batch reactors. The possibility of generating gas for a real application using these concepts is yet to be demonstrated. A number of laboratory and field studies have been made to explore the possibility of using agrowastes for producing biogas.

The review of Meier (1982) discussed the possibilities of using water hyacinth for biogas production. Chopped or mashed water hyacinth has been found to be quite suitable for biogas generation. A more recent review on water hyacinth by Gopalakrishna (1989) gave a fairly detailed description of the work in India on the use of water hyacinth. Most of the experiments used a mixture of water hyacinth and cowdung. The report by Sohani, Joshi (1986) examined a large number of agrowastes/leafy biomass for their biogas potential through laboratory batch reactors. Pilot studies in biogas plants were also made by them on the use of Palas meal, sugarcane trash, and sunflower stalks However, the biomass was mixed with a large amount of cowdung (80–90%) before being fed to the biogas plants.

More laboratory studies were reported by Sharma *et al.* (1989) on the biogas potential of biomass like wheat straw, rice straw, and banana peels. They have reported a good potential for biogas from such leafy biomass.

Most of the earlier studies seem to emphasize the need to mix cattle dung with the other biomass feedstock. The biomass also needs to be chopped into pieces. Apparently these requirements may have stemmed from a desire to use conventional biogas plant design with the new feedstock. Some preliminary studies by Jagadish *et al.* (1987) showed the unsuitability of biomass feedstock in conventional biogas plants. The problem appears to lie in the fact that the conventional biogas plants essentially use a liquid feedstock. The biomass feedstock, even when partially mixed with dung, remains a two-phase material with the liquid and solid components tending to segregate. It was hence felt that there is a need to explore alternative biogas plant designs which could accommodate the two-phase nature of the feedstock.

Potential of leaf biomass in India

Biomass is often mentioned in the context of energy requirements. However, this biomass invariably refers to woody biomass which can be burnt to generate energy. It is rare that leaf biomass is referred to as a source of energy. Leaves are essentially regarded as feed for livestock and are automatically eliminated from any consideration as a source of energy. This perception among energy planners can sometimes lead to a paradoxical situation. Several countries in the world produce large quantities of leafy biomass. However, they may also be perennially short of energy due to excessive dependence on a fossil-fuel economy. The obsession with fossil-fuel resources is responsible for a total neglect of a local and abundant resource like leaf biomass. The problem is compounded by the fact that conversion of leafy biomass to gaseous fuels has not been easy and the R & D in this direction is scanty.

This point may be demonstrated by looking at the biomass energy resources of India. The annual biomass production in India was estimated by the author for the year 1990/91. The break-up of the biomass grown every year [on a dry weight basis in million tonnes (mt)] is shown in Table 1.

TABLE 1
Annual biomass growth in India: 1990/91

Land-use category	Woody biomass (mt) (dry)	Leafy biomass (mt) (dry)	Other low lignin biomass (mt) (dry)
Forests	137.7	374.00	—
Social forestry	67.5	81.00	—
Village forests	29.0	29.00	—
Agriculture	—	382.30	146.5
Weeds	—	80.00	—
Wastelands	45.0	180.00	—
Total	279.2	1126.30	146.5

It is clear from the table that the major biomass grown in India is leaf biomass. Firewood production is nearly one-fourth of the annual leaf biomass production. The preponderance of leaf biomass is perhaps obvious. Leaf development is the precursor of the formation of lignin-rich woody biomass. Accordingly, the annual leaf growth is much more than the formation of wood which is essentially a slow-growing biological resource. The fodder used by livestock is obviously a part of the annual leaf biomass production. A study by Gadgil, Sinha, Pillai (1989) estimated the annual fodder demand at 613 mt for the year 1991. This means that a substantial amount of leaf biomass (which is not consumed by livestock) is available for utilization as an energy resource. However, even this biomass may be currently providing organic matter to the forest and agricultural lands. Any deployment of leaf biomass for energy should not deprive the soils of the organic nutrients. This points to the fact that the only possible route to provide energy as well as organic nutrients is by biomethanation of leaf biomass.

It is possible to make a simple estimate of the total leaf biomass needed to meet the cooking needs of villages. Assuming an average population of 1200 for a typical Indian village, it will need about 300 m^3 of biogas everyday for purposes of cooking. About 900 kg of dry leaf biomass are needed every day to produce this much biogas. This also means that on a national scale, about 160 mt of leaf biomass is needed every year for producing biogas to meet rural cooking needs. If cowdung is used in conjunction with leaf biomass, nearly a third of biomass is saved and only about 107 mt of leaf biomass per annum may be needed. This is hardly 10% of the total leaf biomass grown in India. It must be pointed out that our biomass energy resources are indeed quite significant when compared with our annual energy consumption. However, even this biomass energy is the result of a very lopsided land management. India has the potential to produce a much larger quantity of biomass. A doubling of food production can readily double our straw availability in rural areas. A better management of our wastelands can also boost the biomass availability Improved agriculture, wasteland reclamation, and judicious water management can lead to a vastly enhanced supply of biomass in rural India.

Plug-flow biogas plants for leaf biomass

The past experiments clearly showed the unsuitability of traditional designs in converting leaf biomass to biogas. The author had seen two rectangular biogas plant designs at Trichur in Kerala and at Gandhigram in Tamil Nadu which were based on kitchen waste and leaf biomass feedstock, respectively. It then became obvious that a shallow digestor, rectangular in plan, would be useful for leaf biomass The feeding could take place at one of the narrow ends and the spent material could be removed from the other end. Plug-flow type of designs are hence desirable. Such designs were also mentioned by Meier (1982) while discussing biogas generation from water hyacinths.

The plug-flow reactors of rectangular design were developed and constructed at IISc. The plants were operated for more than three years with occasional stoppages of two to three months. The stoppages were utilized for design modifications and correction for operational problems. A variety of leaf biomass like *Withania somnifera*, *Parthenium*

hysterophorus, and *Synedrella nodiflora* were used for feeding the biogas plants. The plants were always fed with either fresh leaf biomass (before 24 hours from the time of harvesting) or after dipping the fresh biomass for a day in water. The feeding was carried out on the five working days of a week. The spent biomass was removed once in a week. The details and the average performance of the two biogas plants are summarized in Table 2. Figure 1 shows the typical sketch of a 0.6 m^3/day biogas plant using biomass.

The 5 m^3/day plant appears to show a better performance than the smaller plant. It must be pointed out that the large plant had a masonry cover with water storage on top, and the slurry temperatures were generally higher than those in the smaller plant.

A number of features of the new plant design need to be noted.

- The leaf biomass gas plant does not need water feeding every day.
- The use of a masonry vault cover also facilitates the construction of a simple solar water heater at the top to improve digester temperatures.
- A small floating drum gas holder may be connected to the biogas plant to control gas pressure.
- The spent feed can be used for vermicomposting or for mushroom cultivation after mixing with paddy straw.
- Gas yields from leaf biomass are generally better than those from cattle dung.
- It is possible to use cattle dung in conjunction with leaf biomass in these plant designs.
- The biomass can be compressed in a manual press to improve the density of biomass inside the gas plant.

Problems and tasks

The research results reported here refer only to fresh leaf biomass. A couple of attempts to use dried leaf biomass have not been very encouraging. There is hence a need to explore simple methods for processing dry leaves. It has been noticed that dry leaves from trees often collect in large quantities leading to problems of disposal. There is hence a need to utilize this biomass in seasonal biogas plants.

TABLE 2
Details of plug-flow biogas plants

Parameters	Plant I	Plant II
Capacity of gas production (m^3/day)	5	0.6
Nature of construction	Fixed cover; masonary digestor; masonary vaulted gas holder	Fixed cover; masonry digestor; galvanized iron gas holder
Biomass feed rate (kg/day)	50–100	10
Specific gas yield (litres/kg TS)	250–350	200–300
Cost of plant (Rs)	27 000	8000

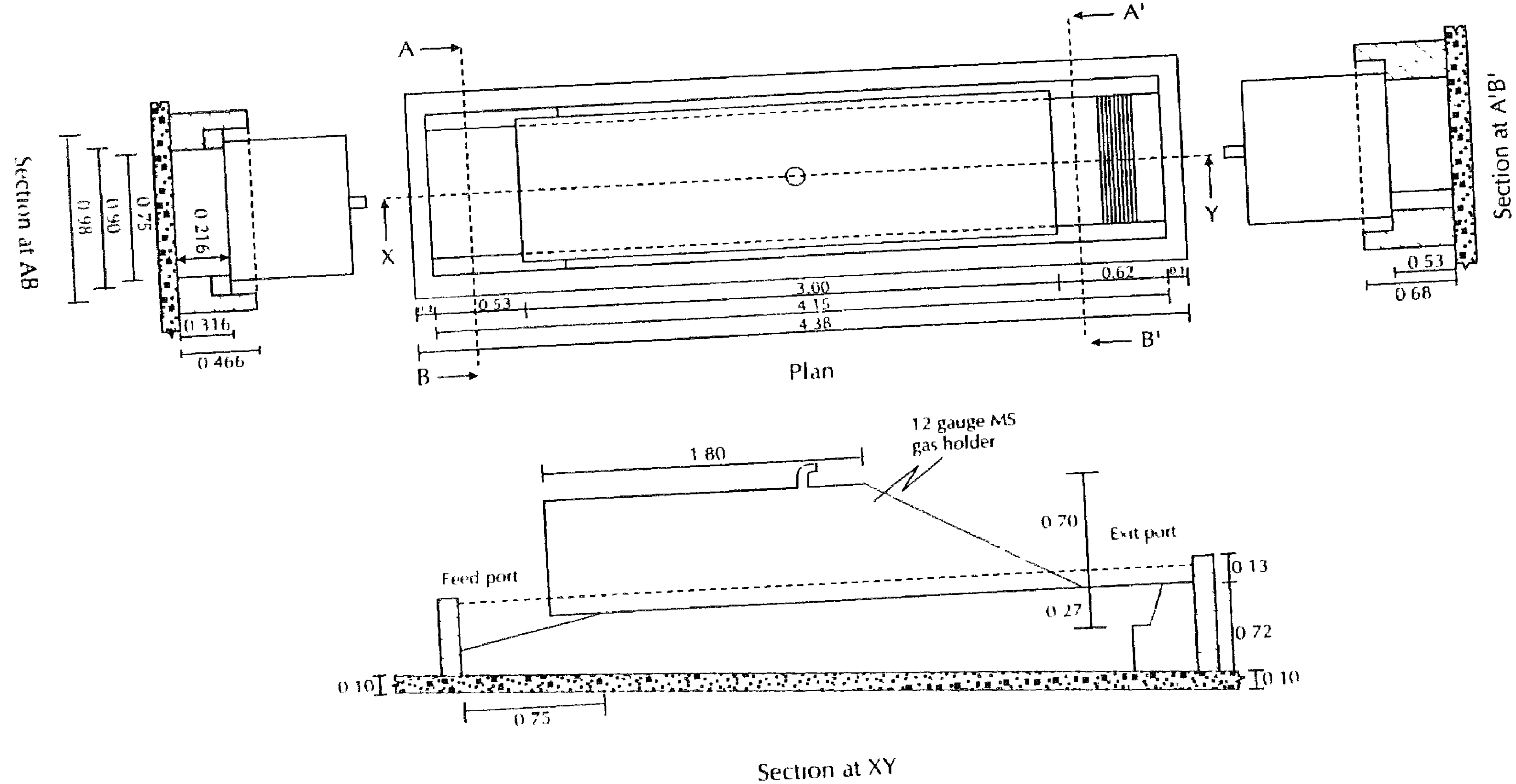


Figure 1. A plug-flow biogas plant

Note. All dimensions are in metres (digester volume = 1.5 m³

There are also quite a few trees and plants whose leaves do not decompose readily either due to the presence of toxins or due to wax coatings which do not facilitate easy decomposition. There is a need to develop methods of processing such leaves.

The availability of biomass for fermentation is another grey area which needs urgent attention if the current research has to make an impact. A systematic screening of various plants for suitability for biomethanation and an assessment of their availability need to be carried out simultaneously. Possibilities with marine biomass offer an opportunity to harvest ocean resources in coastal areas.

The costs of the leaf biomass plants are, in general, somewhat higher due to unfavourable surface, area volume ratio. There is also a need to search for cost-effective construction material and methods as well as better design for the biogas plants.

Conclusions

- The use of leaf biomass for biogas offers opportunities for meeting rural cooking needs, besides generating large quantities of organic manure.
- Plug-flow biogas reactors can be used effectively for generating biogas from a variety of leaf biomass feedstocks.
- Screening of various plants for their biogas potential and research on dry leaf-based biogas plants is necessary for the full utilization of the concept.
- Further research on biogas plant designs and materials is needed for cost reduction.

Acknowledgements

The financial support provided over 10 years by the Ministry of Non-conventional Energy Sources for this research is gratefully acknowledged. The inspiration for this work was provided by the late Dr R S Gopalakrishna in the 1980s. Mr P Rajabapaiah and Dr H N Chanakya of ASTRA collaborated with the author in developing the plug-flow reactor designs.

References

Brakel J V 1980 *The Ignis fatuus of biogas.* Delft: Delft University Press

DST. 1981. *Biogas technology and utilisation a status report.* New Delhi: Department of Science and Technology

Gadgil M, Sinha M, Pillai J 1989. *India: a biomass budget.* Bangalore: Indian Institute of Science, Centre for Ecological Sciences

Gopalakrishna K S 1989 *Energy from water hyacinth a report of task force* Bangalore· Indian Institute of Science, Department of Microbiology and Cell Biology

Jagadish K S 1987 *Solid phase fermentation of biomass to biogas.* Final Project Report to DNES. Bangalore ASTRA, Indian Institute of Science.

Meier U 1982 *Biogas from water hyacinths* SRAT St Gallen Switzerland
Sharma S R. 1989. Biogas from biomass *Indian Journal of Rural Technology* 1(1) New Delhi: CAPART
Sohani G G, Joshi A L. 1986. *Field trials on utilisation of agricultural wastes for biogas production.* Pune: Bharatiya Agro-Industries Foundation.

ECONOMIC DESIGN OF BIOMETHANATION

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Background

Biomethanation in the domestic sector from cattle dung has been introduced in India as far back as 1952. The floating dome model plant, named as the Khadi and Village Industries Commission (KVIC) model, has been the only design, especially for capacities of 10 m^3 and above till now. The National Project on Biogas Development (NPBD) was launched in 1982 with two models, the KVIC floating dome and the *Janata* fixed dome model (Figures 1 and 2) During the year 1985/86, another model, the *Deenbandhu* fixed dome biogas

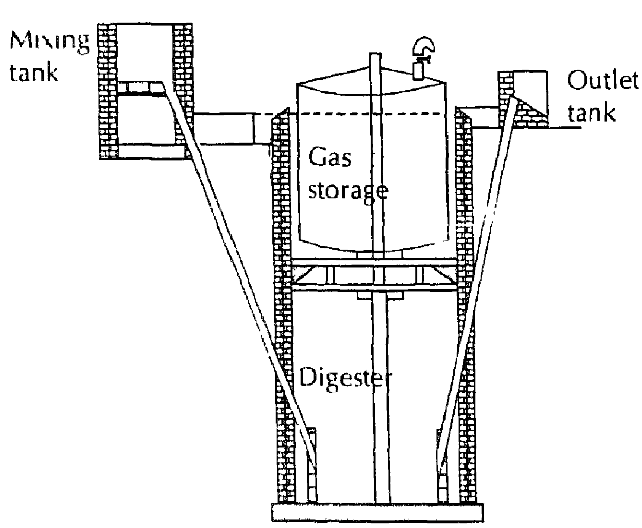


Figure 1. The floating gas holder type biogas plant (KVIC model)

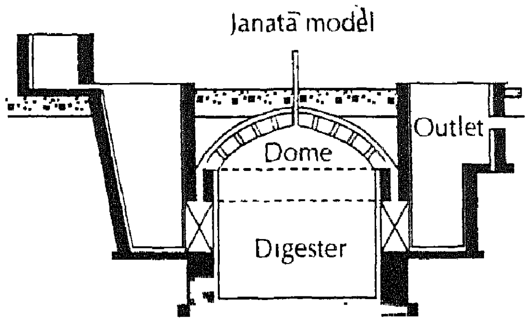


Figure 2. The Janata model

plant (Figure 3) was introduced, which was cheaper compared to the earlier two designs. Till 1995, about 2.3 million family-type biogas plants were installed in India, out of which more than 50% were of the *Deenbandhu* model.

Though NPBD provides subsidies to partially meet the cost of the plant, the rise in the cost of the building materials has been a growing concern. The possibility of the total withdrawal of subsidies in the process of economic liberalization should be a good incentive for the researchers to design low-cost plants so that biogas technology continues to be promoted.

The other reasons for this search for an alternative design have been based on the feedback from the commissioning of the *Deenbandhu* plant. These are listed below.

> Kiln-burnt bricks for the construction of the gas dome is a dire necessity, high precision in construction is absolutely essential.

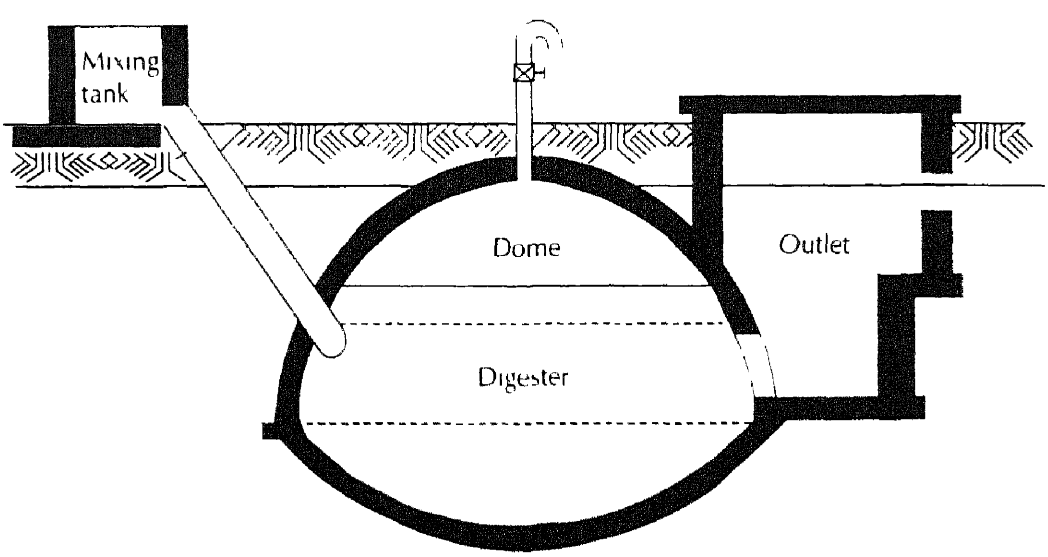


Figure 3. The *Deenbandhu* model

- Curing the structure, specially the gas dome, is mandatory; unfortunately, this is neglected by the implementing agencies, since the trend has been target-oriented and commercial rather than the safeguarding of quality. The beneficiary is not adequately cautioned about the results of scanty and intermittent curing.
- Inside plastering and water-based Epoxy painting for the gas dome needs to be done with utmost care
- Any compromise in the quality or quantity of building materials reflects on the functionality of the plant.
- Delays in the assembly of building materials and in the labour contribution by the beneficiary for the construction of the plant stretches the commissioning period to nearly 40–45 days against the theoretical period of 21 days

Eliminating the above constraints, an 'off the shelf/readymade' plant has been designed and commissioned in Bhubaneswar, Orissa. The plant is a fixed dome model and adheres to the technical dimensions of 2 m^3/day, 40 days hydraulic retention time (HRT) *Deenbandhu* model plant (Figure 4)

The plant and its components

Digester

The digester of the *Deenbandhu* plant is a cement concrete structure 75 mm thick and is a segment of a sphere. This is replaced by the Bentonite liner system in the new design

Bentonite liner system

- This is a recent innovation and extensively used in the US and Europe for lining of waste disposal facilities

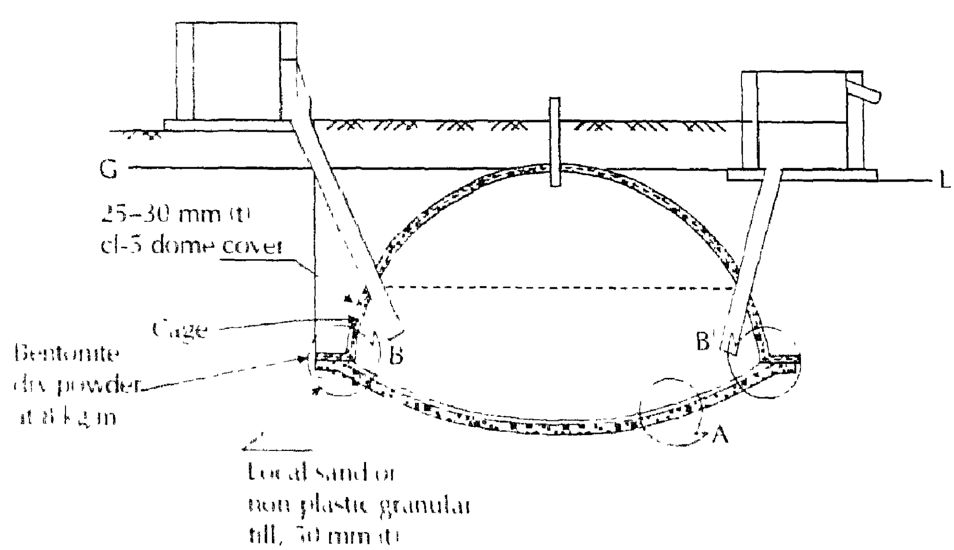


Figure 4. The Bentonite liner CL-5 model

- This system has the potential to replace thick polymer/concrete linings.
- The bentonite liner system is a self-sealing system and exhibits very low permeability. Once dry, the bentonite powder gets soaked and forms a gel
- This system is virtually resistant to chemicals extruded from the leachets.
- The bentonite contained between two fabrics with a layer of sand below is free from the hazard of being washed away by internal erosion and is not subjected to cracking under varying conditions of moisture change.

Bentonite earth and the choice as the alternative

Bentonite earth is an important naturally occurring clay of the montomorillonite group. It is commonly of two types, one is the swelling type and the other non-swelling. Sodium bentonite is generally used as a binder in the preparation of pellets, foundry, drilling mud, ceramic moderators, etc. It is also used for water impedance (preventing seepage from reservoirs, irrigation ditches, waste disposal ponds, and seepage through walls, tunnel walls, and other structures). One of the unique uses of the high-swelling bentonite, more often so in the US, is in the 'slurry trench' or 'diaphragm wall' method of excavation in construction areas of unconsolidated rocks or soil Here, bentonite prevents water seepage and also the caving and running of loose soils in the excavated portions.

It is this property of bentonite earth that encouraged the innovators to replace the conventional cement concrete digester of the *Deenbandhu* plant with this powder Three plants were experimented using this alternative in the plants of beneficiaries in the year 1992/93, with great success

However, for the use in the biogas context, the powder should be sodium-based and have the properties listed in Table 1.

Bottom synthetic coated fabric

This is a 6–7 m wide, a 125 gm/m^2 composite of low density polyethylene (LDPE) black melt coated high density polyethylene (HDPE) slit tape fabric This fabric should have a minimum breaking strength of 880 kg/m in the warp and weft direction with 20% deformation when tested as per IS 1969

TABLE 1
Specific properties for the bentonite earth to be used in the biogas system

Physical properties	Chemical properties
Swelling index: 21 times (liquid limit: 300%)	SiO_2: 48–58%
Gel index: 20–31	Fe_2O_3 3–11%
pH 9.05–9.80	Al_2O_3: 19–25%
Loss of drying 7 11–11 20	TiO_2. 0 31–0 94%
Specific gravity: 2–2 69%	Ca O 0 56–2%
	MgO 1–2%
Permeability 10^{-7} cm/second	Na_2O. 1.25–1.89%
	K_2O 0.42–1.14%

Top synthetic uncoated fabric

A 6–7 m wide of HDPE black slit tape fabric (12 × 12 or 10 × 12 mesh) weighing a minimum 60 gm/m^2, this fabric should have a minimum breaking strength of 880 kg/m in the warp and weft direction with 20% deformation when tested as per JS 1969.

Laying of the bentonite liner

The sequence of construction will adhere to the dimensions of the digester specified in the manual of the *Deenbandhu* biogas model.

- The pit is excavated as per specifications with special emphasis on the radius of curvature of the digester.
- 50 mm thick sand is spread on the curvature.
- LDPE black melt-coated HDPE bottom fabric is spread in the curvature, and in the flat projected portion of 200 mm wide at the top end of the curvature, i.e., 'A' and 'B'.
- Dry bentonite powder @ 8 kg/m^2 is spread over the bottom fabric. The powder must be spread uniformly throughout. In case of any problem in spreading the dry bentonite powder, the powder is mixed with water, made to a gel, and then pasted uniformly over the bottom fabric.
- The top fabric, i.e., the HDPE black slit tape fabric is spread over the bentonite coat layer.
- 50 mm thick cement concrete (1:3:6) is spread at 'A' and over the bentonite liner.
- Thus, the bentonite powder is sandwiched between two layers of synthetic fabric and a bentonite liner is formed. The liner, after the absorption of water, serves as a virtually impervious barrier/septum.

Precaution

- The overlapping of fabric (both bottom and top) if required should be 150–200 mm. Alternatively, both the fabrics can be stitched.

Problems

- Bentonite powder, once absorbed in water, becomes slippery. Movement over the liner should, therefore, be carried out carefully.
- Bentonite liners may exhibit some seepage initially. This would continue until the bentonite is fully saturated and forms an impervious cake. Seepage through the bentonite liners in the initial stages are of no consequence and should not cause any concern

Advantages

- A bentonite liner is cheaper than the conventional 75 mm thick (1:2:4) cement concrete (c.c.) layer at the bottom segment.
- A bentonite liner provides a protective lining and ensures required stability against side-wise earth pressures and is impervious against external seepage as well.
- The liner can be constructed in any type of soil, and can tolerate deformations caused by the dimensional changes in the sub-soil. It can also resist external or internal pressures

- It completely dispenses the use of chips and cement.
- It is easy to construct and saves time and manpower

The dome

The gas dome of the *Deenbandhu* model is of brick masonry construction with a uniform thickness of 130 mm. The mandatory needs of the construction include·

- kiln-burnt bricks;
- perfection in the inside-plastering of the dome;
- water-based Epoxy on plastering to be of excellent quality;
- curing for 11–13 days; and
- training of masons for skilful construction.

The new design eliminates the need for all the above mandatory precautions due to the use of a readymade CL-5 material sheet as the dome for the plant

The CL-5 material

For obvious reasons, the manufacturer of this material, M/s Texel Plastics Ltd, Mumbai, have not revealed the composition of this material. However, their assurances about the CL-5 material include those listed below

- It is India's first branded polyethylene tarpaulin.
- It is ultraviolet stabilized.
- The joints are stitchless.
- It is impervious.
- It can be supplied duly laminated with natural fabric, which can be coated at the site with a cement stone dust slurry for 100% ultraviolet and puncture resistance.

Dome construction

The dome is a hemisphere with a diameter of 2 5 m and surface area of 11 m^2 (2 m^3/day capacity) The CL-5 material is 100 mm wider than this for stabilizing it by embedding throughout in the bottom periphery of the hemispherical configuration (Figure 4). 6 mm MS rods and an MS flat on the edge position were used to form the cage of the dome (Figure 5) to the exact specified dimensions. The CL-5 material was covered *in situ* over the case and the excess width of 100 mm was covered with c.c. for 1:3:6 which was 100 mm wide and 200 mm high to embed the sheet and protect it against possible 'lift' due to the gas pressure. A similar treatment to the bottom ring of the hemispherical cage was done for stabilizing the structure. Over the surface of the dome, a thin layer of cement stonedust slurry is provided throughout to add more weight as a counter to gas pressure.

Advantages

- The dome can be erected within a couple of hours
- This can be folded and carried on a bicycle by the masons to the site.
- It saves time, manpower, and money.

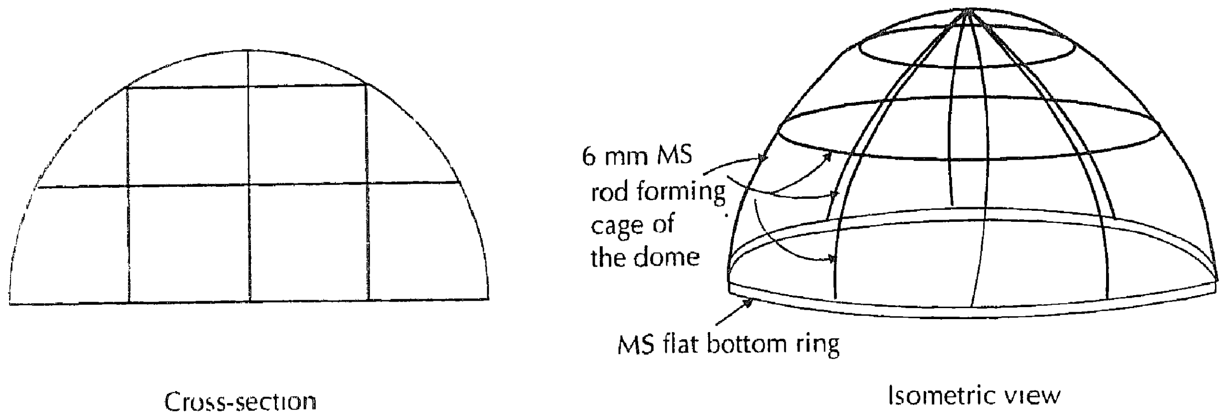


Figure 5. Cage for the dome

Pressure tank

Matching the cubic content of pressure tank of *Deenbandhu* plant, the outlet/pressure tank of this plant is an assembly of 2 reinforced cement concrete rings, 1.21 m in diameter and 0.3 m high. This is connected by an AC pipe to the digester, whereas, in the former model, the pressure tank becomes monolithic after construction.

All other components

The inlet tank, inlet pipe, and gas distribution system follow the guidelines of the *Deenbandhu* model.

Results

The plant was commissioned as per the above chronology, and results observed are listed below.

- Methanation of the organic matter used (cowdung) has been ideal for a 40 days HRT plant. The rate of gas generation matched the cubic content design as per the measurements conducted.
- The pressure was restricted to 40 cm of the water column. The *Deenbandhu* model is designed for 100 cm of the water column for structural reasons The CL-5 material will be tested for its resistance to the maximum pressure.
- The plant's erection took exactly 8 days with a manpower of 4 mason days and 10 labour days

The plant is operative and under observation.

Anticipated risk factors

- Once the demand for biogas plants construction goes up, the quality aspect of, bentonite powder has to be watched as the traders, specially at the block level, may

adulterate the powder In the enthusiasm of economizing on the cost, if this factor is neglected, then the quality of plants will deteriorate

- The top and bottom sheets during transportation may get punctured due to improper care This small loss may result in the plant becoming dysfunctional.
- The structure has to be fenced off with thorny bushes/barbed wiring against possible trespassing of cattle or children over the dome
- The joints of asbestos cement inlet and outlet pipes with the CL-5 material must be sealed perfectly to arrest the slurry and gas seepage and leakage respectively.
- Imperfect fabrication of the cage of the dome will change the shape and size of the dome.
- Since the manufacturer does not specify the reactions of acids/alkalis/gas on the material, the CL-5 material must undergo at least 12 months of wear and tear tests for its life The *Deenbandhu* model guarantees a life of 15 years Both the bentonite liner system and the CL-5 sheet should have at least a 10-year lifespan from their cost price for customers' acceptance.

Methodology of field-level implementation

- Each block of the state will have to have a construction-cum-demonstration plant backed with all literature of the materials and the methodology of construction details.

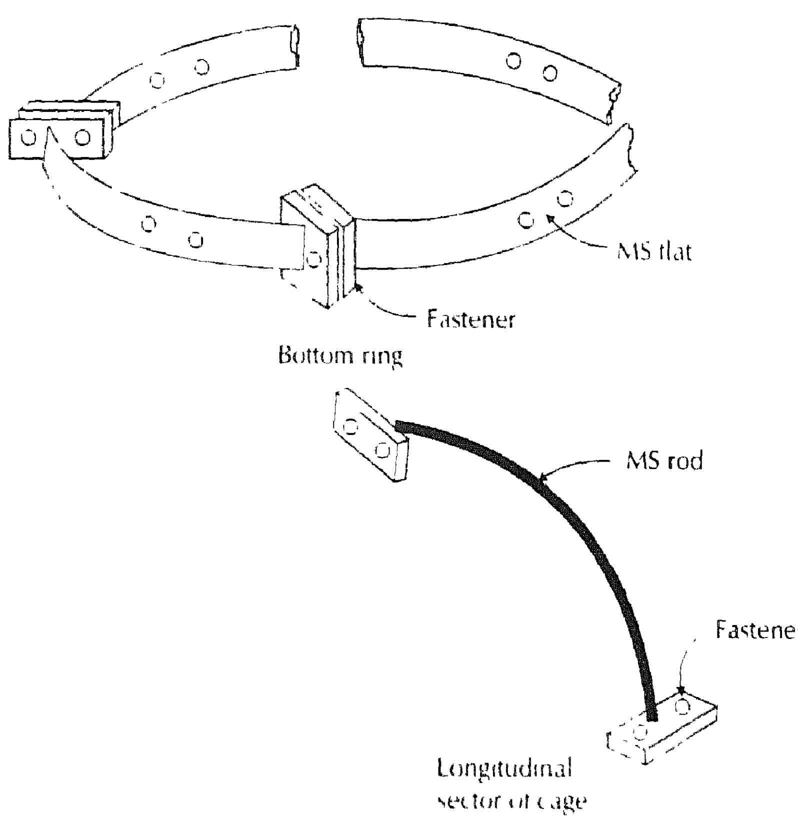


Figure 6. Concept of the *in situ* cage assembly

- The assembly of the dome's cage at site could be simplified avoiding welding or carrying the prefabricated cage (Figure 6).
- All cement dealers in the rural areas must be made aware of the need for stocking bentonite powder and LDPE and HDPE sheets of the size needed for 1–4 m^3 size of the fixed dome *Deenbandhu* model plant. Other accessories for the biogas plant are already available in such stores.
- The CL-5 material, as per the cubic capacity of the plant, must be procured centrally by the implementing agencies direct from the manufacturer for further decentralized distribution.

The economics

Annexure I provides the economies of cost, time, and labour. The rates are the average rates prevailing in the state of Orissa.

ANNEXURE I

The economies of material cost, time, and labour for the *Deenbandhu* model biogas plant and the bentonite liner CL-5 material biogas plant

Deenbandhu model plant

Material	Rate (Rs)	Quantity	Cost (Rs)
Brick	1000/1000 nos	1000 nos	1000
Cement	140/bag	140 bags	1960
Stone chips	350/m^3	1 15 m^3	400
Sand (coarse and fine)	70/m^3	2 m^3	140
GI pipe 12 mm diameter with sockets	Lump sum	29 cm long	30
AC pipe 100 mm diameter	30/m	2 m	60
MS iron bars 6 mm diameter for outlet-tank cover	16/kg	10 kg	160
Epoxy paint	140/litre	1 litre	140
Labour (pit digging)	40/day	10 days	400
Mason	60/day	11 days	660
Labour (plant construction)	40/day	22 days	880
Miscellaneous and transportation	Lump sum	—	200
Total	—	—	6030.00

Bentonite liner - CI-5 material plant

Material	Rate (Rs)	Quantity	Cost (Rs)
Sand	70/m^3	0.5 m^3	35
HDPE slit tape fabric @ 60 gms/m^2	120/kg	0.5 kg	60
LDPE melt coated HDPE slit tape fabric @ 110 gms/m^2	180/kg	0 9 kg	160
Dry bentonite @ 8 kg/m^2	5/kg	64 kg	320
CL-5 material 11 m^2	Lump sum	—	900
Dome cage	Lump sum	—	300
Outlet and inlet tanks of 1 2/m diameter and 0.3 m high	140/ring	3	420
Labour (pit digging)	40/day	6 days	240
Mason	60/day	4 days	240
Labour (plant construction)	40/day	8 days	320
Foundations of both inlet and outlet	Lump sum	—	3000
Miscellaneous and transportation	Lump sum	—	200
Total	—	—	3495

The costing is exclusive of the distribution system for both the plants.

ADVANCES IN MATERIALS TECHNOLOGY IN OPTIMIZATION OF BIOGAS PLANTS

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Introduction

It is estimated that about 12 million biogas plants can be set up in India, of which only 2.3 million plants have been installed so far. Meeting the target seems to be an uphill task particularly because of increasing costs of conventional construction materials e.g., cement, steel, and bricks, and the time required to construct a single plant of household size.

For instance, a family size *Deenbandhu* model biogas plant, of 2–4 m^3 size costs Rs 5000–8000 in India. The subsidy provided by the central government varies from 33 to 50%. This implies that the beneficiary has to invest about Rs 2500–4000 as the case may be from his own resource. The majority (about 60–70%) of biogas users belong to the poorer section of the society and considering their economic status, the initial investment as well as the cost of operation and maintenance (O & M) are beyond their reach.

Advantages of advances in materials technology are already visible in the construction of buildings and roads. It has now been possible to build reinforced soil or crib retaining walls, hydraulic structures, earthquake-resistant buildings and reinforced road bases. For all these major applications, consumption of energy-intensive materials in construction and transportation has been brought down significantly with no compromise on performance.

It was recognized at the outset that the biogas plant designs currently in use are essentially efficient and need no major modifications with regard to size and geometry. The successful experience of materials technology for other applications can now be extended to construction of biogas plants to save cost and time substantially. The focus has been,

therefore, to bring down the costs to an extent that the biogas plants would become affordable. For instance, reinforced soil or crib technology can be extended to build vertical walls of gas digesters of the Khadi and Village Industries Commission (KVIC) type, synthetic membranes laminated with natural non-woven fabrics placed on a structural cage of steel-bamboo composite can be used to construct gas holders, and bentonite or clay liners can be used for the lining of digester bases

This paper presents details of the use of alternative materials and construction techniques for 2–3 m^3 *Deenbandhu* and KVIC biogas plants of larger capacities, which would serve the rural poor on a community basis. Here, the experience of village Pura in Karnataka is particularly relevant, where it has been demonstrated that a community-size biogas plant fed primarily on leaf litter meets the requirement of fuel and electricity for pumping of drinking water and lighting of the entire village.

Optimized *Deenbandhu* model

Construction of lower hemisphere

Currently, the lower hemisphere of the *Deenbandhu* model is constructed in concrete, which is expected to perform the functions of a barrier to prevent seepage as well as to withstand settlements in the ground and uplift caused by the build-up of pore pressures during settlement in the groundwater table PCC or RCC is designed to meet the requirements as necessary. However, concrete linings are expensive and often do not satisfy the performance requirements.

In the suggested alternative design, concrete is replaced by a bentonite or clay liner which is an excellent barrier to seepage and is sufficiently flexible to withstand settlement as well as to resist uplift pressure without compromising the barrier function. In addition, a grid reinforcement of bamboo/palm mid rib can be provided in situations, where excessive soil settlement is apprehended

Bentonite or compacted clay liners are now increasingly used in the developed countries for seepage control of water storage structures and effluent storage facilities. Bentonite liners used abroad are assembled in the factory by sandwiching bentonite between layers of synthetic fabrics Bentonite clay has a unique property of forming an impervious cake on hydration, which exhibits excellent self-healing characteristics under confined conditions Hydrated bentonite cake continues to perform the barrier function as long as drying or washing away of bentonite is prevented Bentonite liners formed from synthetic geotextile are expensive under Indian conditions, due to relatively high cost of synthetics.

Bentonite or clay liner suggested herein uses a judicious combination of natural and synthetic fabrics to keep the input of costly synthetic fabrics to bare minimum without compromising the performance.

Step 1

A 50 mm thick layer of locally available sand (even dirty silty sands are permitted) is placed on a well compacted base

Step 2

A natural non-woven fabric (jute, coir, banana, pineapple) laminated with a lightweight slit tape synthetic fabric is placed over the sand layer. Alternatively, two fabrics, i.e., natural non-woven and high density polyethylene (HDPE) slit tape fabric brought separately can be attached by hand stitching. HDPE slit tape fabric recycled from empty bags of cement has been successfully used by the Orissa Renewable Energy Development Agency (OREDA) during prototype trials.

Function

The sand layer in conjunction with natural non-woven fabric laminated with HDPE fabric forms a good filter, which prevents the erosion of bentonite. Degradation of the natural fabric is of no consequence in the presence of layers of sand and HDPE slit tape fabric. In areas infested heavily with crabs and rodents, the natural fabrics should be coated with cement slurry.

Step 3

Dry bentonite powder is spread uniformly on the fabric base. A non-woven fabric facilitates placement of bentonite powder as the fabric provides a typically rough fibrous surface.

Function

Bentonite powder on hydration forms an impervious cake and provides a leak-proof septum or a barrier layer Bentonite is a naturally occurring clay and, therefore, does not react with effluents. The barrier characteristic of bentonite is, thus, not impaired with age.

Step 4

A cover layer of fabrics is placed and a thin coat of plasticised cement slurry is applied and allowed to set. This completes the construction of the lower hemisphere and the entire operation can be accomplished in half a day by the beneficiary family assisted by a technician.

Construction of upper hemisphere

Conventionally, the upper hemisphere is made in brick masonry. The construction of the upper hemisphere in brick is a skilled work and requires close control during construction which takes about 15 days to complete.

In the alternative design, the upper hemisphere is constructed by a pre-assembled steel-bamboo or a palm mid rib structural cage covered by a prefabricated impermeable, tough, and puncture-resistant reinforced synthetic membrane laminated with a natural non-woven fabric, coated with a slurry of cement–fly ash–stone dust The construction of the upper hemisphere is described below

Step 1

A steel rod skeleton is fabricated by welding

Function

To control the geometry of the upper hemisphere.

Step 2

Preservative-treated bamboo or palm mid ribs are attached to the steel skeleton. Attachment of bamboo or palm mid rib strips to steel rods require a specially developed joining method which is developed for other applications, e.g., the reinforcement grid for road bases. The bamboo or palm mid rib and steel rods are portable and, therefore, can be assembled in advance in a factory shed.

Step 3

A prefabricated cover of reinforced membrane is unfolded and placed on the structural cage of bamboo/palm mid rib. Prior to this, a mauled plastic piece with neoprene washers and nuts for the gas outlet is fixed to the reinforced membrane cover.

Function

The prefabricated reinforced membrane cover, being lightweight, is easy to handle and install. At the same time, it is sufficiently tough and impermeable to prevent the leakage of gas. It is also amenable to testing before installation. The cover can be inverted and filled with water to verify leaks if any and defects rectified as required or returned to the manufacturer.

Step 4

A plasticized slurry of cement, fly ash, and rock dust is applied on the reinforced membrane covered with natural geotextile. Use of sand should be avoided unless a clean fine sand is available locally The sand particles in the slurry should be fine enough to penetrate the pores of the natural non-woven or woven geotextile. The cement coat should be adequately cured.

Function

A coat of cement slurry on the natural geotextile provides a tough, puncture-resistant layer, and acts as crab and rodent barrier

Step 5

Inlet and outlet pipes are fixed by making holes in the reinforced membrane cover. The gaps around the upper hemisphere are then filled back with sand or sandy clay and inlet and outlet chambers are constructed (Figure 1).

All the operations described as above are completed in two days by the beneficiary family assisted by a technician and a couple of helpers. Masonary skill is not obligatory for the application of cement slurry on the fabric as it is similar to floors using cowdung and soil – an activity routinely handled by women in rural India Activities such as the preservative treatment of bamboo/palm rib, fabrication of the steel rod cage, and manufacture of natural fabrics can be set up in small rural factories. After some more trials and training it is expected that a family-size *Deenbandhu* biogas plant can be constructed

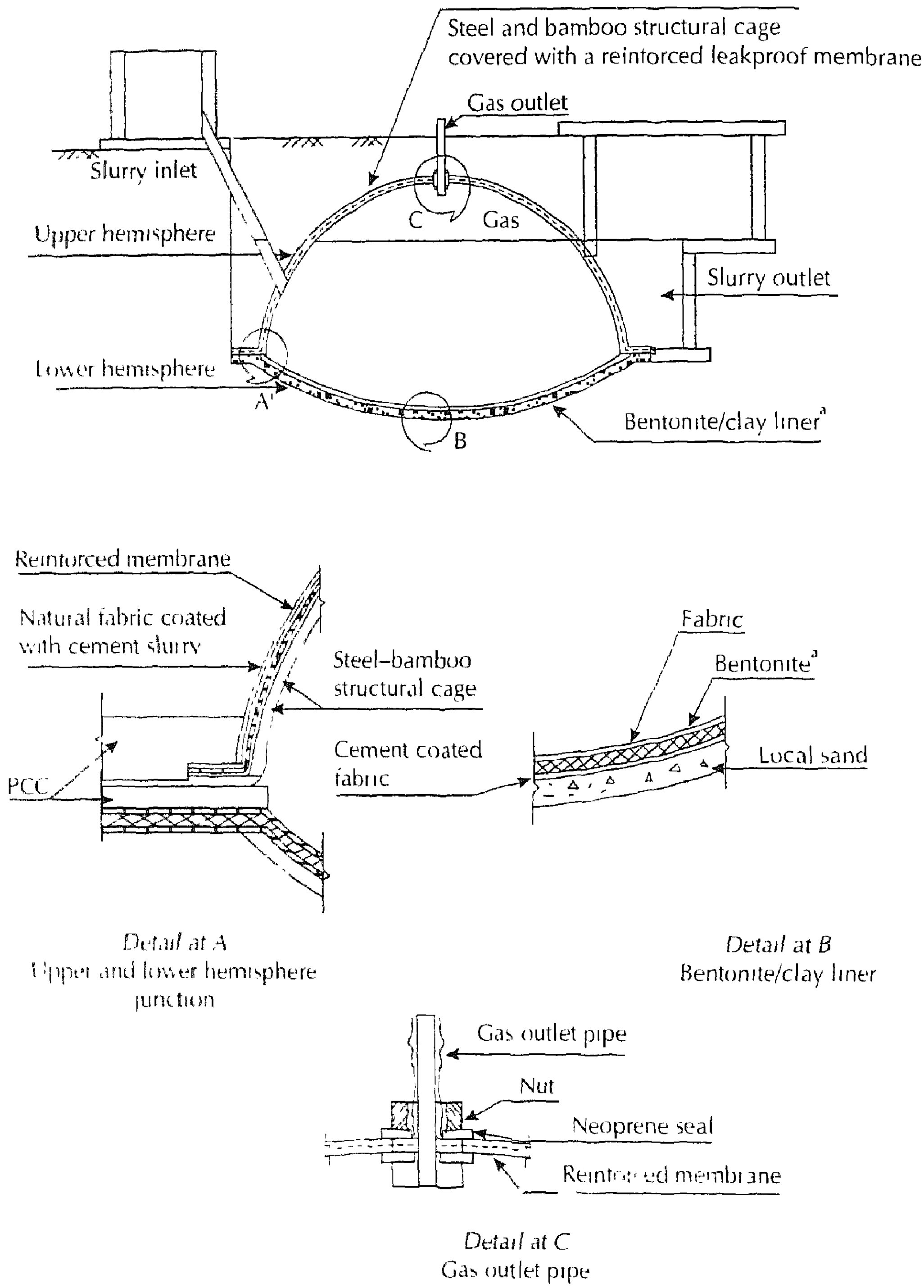


Figure 1 An optimized *Deenbandhu* biogas plant; [a] a local plastic clay or CH or GC group (USBR classification) may be used if bentonite not available

less than two days as opposed to a minimum of 15 days required for the construction of a plant by the conventional method using concrete for the lower hemisphere and brick masonry for the upper hemisphere.

During a training programme at the Vivekanand Kendra in Kanyakumari and adjoining districts in Tamil Nadu, it was found that bentonite was not available. A locally available plastic clay was successfully used. However, selection of clay is a crucial aspect and needs training of the local people. This can, however, be easily done by adopting USBR field classification method which consists of simple field tests. Whenever clay is used, the bottom fabric should be coated with a cement slurry to ensure the efficacy of the clay liner.

KVIC model

KVIC type gas plants are constructed more or less on the same lines (Figure 2). The floating gas holder is made by a steel–bamboo–timber cage covered by a prefabricated tough synthetic membrane. The gas holder by the alternative design is lightweight as compared to the conventional steel place gas holder, and this constraint is overcome by providing additional weight (e.g. sand bags), on the top of gas holder.

The guide frame of the angle iron used currently is replaced by a preservative-treated small timber truss. Timber trusses for spans of more than 15 feet have been used for buildings.

The vertical sides of the gas digester are made in reinforced soil which consist of dry stone facing with bamboo/timber anchored ties to withstand lateral earth pressures. Reinforced soil or crib retaining walls of concrete or stone masonry. The digester base is lined by bentonite or clay liner as described earlier for the *Deenbandhu* model.

The KVIC Bombay centre has planned the construction of prototype plants in the Nasik district of Maharashtra. The results of prototype construction would soon be available but drawing from the experience of prototypes already in service of the *Deenbandhu* model, it is expected that with minor modifications during the prototype trials, the cost of KVIC models can also be substantially reduced.

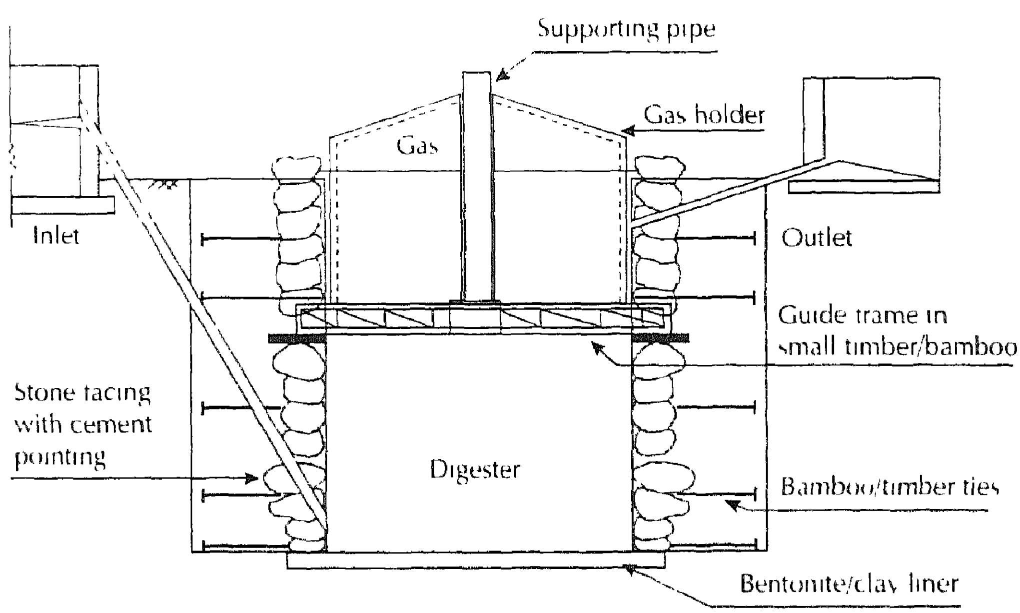


Figure 2. An optimized KVIC biogas plant

Cost comparison and actions for the future

It can be seen from Tables 1 and 2 that savings in cost up to 50% are attained for the upper and lower hemisphere of *Deenbandhu* model with an overall saving of 40%. It is possible to bring about an overall saving of 50% when the costs of slurry inlet, outlet, mixing tank, and expansion chamber are optimized. Here again, new materials technologies would bring down the consumption of cement, concrete and bricks. Tables 3 and 4 present the optimized cost of the KVIC model. The main cost in the KVIC model is that of the gas holder and the digester. The gas holder made in mild steel (MS) is subjected to corrosion which leads to high operational and maintenance costs. It would be seen that with optimization of design, costs could be brought down by 45% for the gas digester and holder.

There is a good scope to bring down the costs further. For example, the bentonite liner described in this paper uses natural non-woven fabric obtained from existing large manufacturers. It has been observed that jute and coir needle punched non-woven fabrics manufactured by the large industry are priced at Rs 40–50/kg although the raw fabrics manufactured in the small industry would be eminently suitable for the bentonite liner application since for this function the requirement of pore size control is not critical as in the case of fabrics used as filters in major structures. The fabric is required to be needle punched only to the extent that a fabric structure is obtained which can be handled to facilitate laying In fact, a carded fabric bonded with resins such as phenolics obtained from natural sources would be the most desired option. Fabrics of small widths can easily be joined by hand. Efforts should be made to set up small rural factories to manufacture fabrics.

Drawing upon the experience of recent advances in the timber–bamboo concrete composite technology for buildings in Maharashtra, the structural cage of bamboo–steel com-

TABLE 1
Optimized *Deenbandhu* model (2 m^3 capacity)

Description	Quantity	Rate (Rs)	Cost (Rs)
Bentonite or clay liner for lower hemisphere			
50 mm thick local sand	0.4 m^3	70/m^3	28
8 m^2 of jute non-woven (200 gsm) laminated with slit tape fabric (60 gsm)	8.0 m^2	10/m^2	80
Bentonite powder	48 kg	1.5/kg	72
8 m^2 of jute non-woven with slurry of cement fly ash	8.0 m^2	15/m^2	120
Concrete at the junction of lower and upper hemisphere	—	—	100
Total			400
Structural cage of bamboo-steel composite covered with reinforced membrane for upper hemisphere			
MS rods (6 mm and 4 mm diameter) (kg)	10	12/kg	120
Bamboo strips with sleeves, wire loops, and binding wire (m^3)	0 05	5000/m^3	250
Membrane (250 gsm) laminated with jute non-woven (250 gsm) (m^2)	10	60/m^2	600
Labour	LS	LS	130
Total	1100	—	—

TABEL 2
Deenbandhu model (2 m^3 capacity): cost comparison of the conventional design resulted in the optimized design

Description	Conventional design	Optimized design	Savings (Rs) (%)
Excavation	300	300	—
Lower hemisphere	900	300	600 (66)
Upper hemisphere	2200	1100	1100 (50)
Inlet and mixing tank	300	300	—
Expansion chamber	700	400	300 (42)
Gas distribution system	600	600	—
Total	5000	3000	2000 (40)

TABLE 3
Optimized design of the KVIC type biogas plant (2 m^3 capacity)

Description	Quantity	Rate (Rs)	Amount
Gas holder			
MS steel skeleton with welded top and bottom rings with spacer rings and plates for bamboo/timber connection including fabrication (kg)	14	35/kg	490
Treated bamboo/timber strips attached to the steel skeleton with sleeves/wire for the joints (m^3)	0.04 m^3	6000/m^3	240
CLS laminated (300 gsm) with jute non-woven (250 gsm) coated with cement-stone dust with plasticiser, etc. (m^2)	6 m^2	80/ m^2	480
MS pipe, galvanized iron bend, gas valve rubber pipe, with labour[a]			470[a]
Guide frame			
Treated bamboo/timber concrete composite with all joints fabrication including pipe, plate, etc.	LS	—	220
Gas digester			
Reinforced soil construction for the sides and bentonite liner for the bottom	LS	—	2000
Total	—	—	3978

[a] costs as in October 1995 furnished by KVIC (Bombay).

posite described in this paper, for the construction of upper hemisphere of *Deenbandhu* model and the floating gas holder of KVIC model, can be fully replaced by bamboo – timber – concrete composite covered with a resin-treated natural non-woven fabric coated with cement slurry. This will further optimize the cost as well as change the input composition of materials.

Efforts should be made to make the biomass-based materials available to the village artisans for value added processing comprising preservative treatment and fabrications. Small timber and bamboo after treatment and processing can be used for making the gas holders, the guide frames, and the vertical walls of the digester. Natural fabrics with

TABLE 4
KVIC type biogas plant (2 m^3 capacity): Cost comparison of the optimized design versus the conventional design

Description	Conventional design	Optimized design	Saving (Rs) (%)
Gas holder	3116	1680	1436 (46)
Guide frame	322	220	102 (31)
Gas digester	3978	2078	1900 (47)
Total	7416[a]	3978[b]	3438[c] (46)

[a] based on costs as in October 1995 furnished by KVIC (Bombay); [b] projected cost of prototype trials; [c] savings are expected to increase during mass-scale implementation.

suitable treatment and processing in a rural factory can be created by the integration of wastelands and watershed development programmes. A consensus among the beneficiaries needs to be created to encourage use of community-size biogas plants. Suggested technologies are eminently suitable for community-size plants. Biogas use need not be restricted to fuel for cooking but to generate electricity for lighting and pumping water for drinking as well as irrigation.

THE BIOGAS PROGRAMME: AKRSP (I) EXPERIENCES

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Background

The Aga Khan Rural Support Programme (AKRSP), India, was established in 1985 to enable the empowerment of rural communities, particularly the underprivileged and women, to take control over their own lives and manage their environment, and to create a better and more equitable society.

This programme has been functioning in three districts in the state of Gujarat, i.e., Junagadh, Surendranagar, and Bharuch. Each district poses its own opportunities and constraints for development. AKRSP initiated its association with rural villages through the process of Participatory rural appraisal (PRA) This exercise is followed by the organization of people into village institutions (VIs) and women's organizations (WOs) around small rural development projects related to land and water. The biogas programme is one such project

The biogas programme was launched in 1986 by technically-qualified civil engineers of AKRSP, who were also trained on process issues, in response to people's needs and the ecological crisis in Junagadh. The Gir National Forest was getting rapidly deforested and Junagadh's once productive soil was becoming saline due to the excessive use of chemical fertilizers. Biogas was an extremely attractive alternative to more expensive 'technical fixes'. As a technology also, a single family can possess and control a biogas plant. This fitted very well into AKRSP's mission of working with village communities on management of their own area's natural resources and achieving a better quality of life for women. Biogas also worked as a complementary programme to AKRSP's wasteland and agricultural development programmes. Later this programme was extended to the Surendranagar and Bharuch districts also

Approach

The biogas programme is being promoted by the local villagers chosen by VIs and WOs and trained by AKRSP on technical and process issues. These villagers are called extension volunteers (EVs). The EVs mainly motivate the villagers for biogas, distribute materials, and supervise the construction of plants. Of late, fully-trained EVs are taking up more and more responsibilities of implementing the programme in a cluster of villages. They are called master extension volunteers (MEVs). The EV model is in line with AKRSP's efforts of making the programme market-oriented and for building up entrepreneurs to expand the programme.

In Bharuch, which is a relatively egalitarian community, the whole biogas programme is being managed by women EVs. In addition, regular and refresher mason camps and meetings are organized for building up a core group of masons. The consumers have a stake in the quality control of the plants as the mason fees are paid by them.

Training of the women users on maintenance and back-up systems has been a major focus over the years. Conducting 'best plant' competitions in villages have also led to an increasing awareness of maintenance issues among the users

Achievements

About 5000 individual biogas (*Deenbandhu* model) plants have been constructed so far across the three districts. As the investment in terms of time and money in this programme increased, questions of cost/benefit were raised within the organization and by donors. A detailed analysis, however, led to a new world where complex questions like actual cost/nominal cost, shadow pricing, assumed value of fuelwood and dung, opportunity cost of labour, etc., seemed irrelevant The hidden benefits beyond the economics of biogas emerged Some of the responses from villages given below well illustrate this point·

- 'The value of biogas cannot be calculated in monetary terms. It has added 20 years to my life'.
- 'We were so afraid of the forest guards. A number of times we used to leave our headloads and sickles and just run away hearing their footsteps. Now, life is different (after biogas)'.
- '300 bullock carts of wood were collected from the nearby forest annually; now it has come down to 15–20 bullock carts'
- 'An average household gets 1.5 to 2 cart loads (30–40 quintals) of manure through slurry against the one cartload of cowdung'.
- 'Biogas is alternative to smoke-producing cooking fuel, and it cleans the environment as well'.

Studies show that the time spent by women in cooking, making cowdung cakes, collecting fuelwood, and washing blackened utensils have come down by six hours per day. Biogas gives women more time to attend to their children's needs; school enrolment among chil-

dren has also increased While cooking on a traditional *chulha*, women and girls inhale large quantities of smoke everyday resulting in a high rate of lung and eye disorders. Women labourers can go on time to their work now and do not miss out on part wages. In addition, women have respite from accidental deaths due to scorpion stings, snake bites etc., while collecting fuelwood in rainy seasons.

Environmentally too, biogas reduces fuelwood consumption; hence there is less pressure on forests Biogas slurry acts as a soil enricher; it reduces weed incidence, and, thus leads to lesser use of weedicides Apart from this, the programme creates demand for casual and skilled manpower, for required materials, and thus builds up rural economy

Then, the question arises: why is biogas still not recognized as a tool for the empowerment of villagers and environment sustainability? This is due to poor documentation, low credibility owing to the high failure rate in the early years, perception of being a subsidy-driven programme and a programme for the rural elite, limited international experience, sectoral approach by the government and non-government organizations, less focus on transfer of technology to women, etc.

Moreover, support from the government to rural energy sector is comparatively low. For *in situ* government subsidy for urban energy sources, i e., kerosene and liquefied petroleum gas is more than Rs 1000 crore/year, while the subsidy on biogas is only Rs 60 crore/year. Environmental protection is subsidized, but biogas is not seen as complementary to the forestry programme.

Nevertheless, biogas could provide an ideal solution for protecting India's dwindling forests and wildlife areas and its growing problems of soil salinity and overuse of chemical fertilizers These plants also offer a better life to rural women. Hence, it is extremely essential that biogas be recognized as a renewable energy programme of national importance.

Section 6

Municipal solid wastes

BIOMETHANATION: AN OVERVIEW

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Introduction

The fermentative process of the conversion of organic matter to a mixture of methane and carbon dioxide gases, commonly known as 'biogas', was traditionally applied for the treatment of waste with the aim of 'stabilizing' it However, over the last two decades, both developed and developing countries have been evincing interest in biomethanation from the viewpoints of pollution control, energy generation, enriched manure production, and health improvement. Besides, various social benefits such as reduction in the drudgery of rural women, better sanitation, improved environment, ecological restoration, etc , accrued due to the installation of biogas production units, have received added importance

Small-scale biogas technology

It is a point to note that in the developing countries, particularly China and India, biomethanation is being practised to stabilize pig and cattle manure respectively on a very large scale Approximately, over 6 million and 2 million small-sized biogas units have been functioning in China and India, respectively. An analysis of their biogas promotion programmes shows that while these countries have not only developed and adopted simple-to-construct and easy-to-operate small-sized biogas production designs (Figure 1), they have also combined it with a sustained political framework and administrative preparedness, and with financial and training support Among other countries, Bangladesh and Nepal have

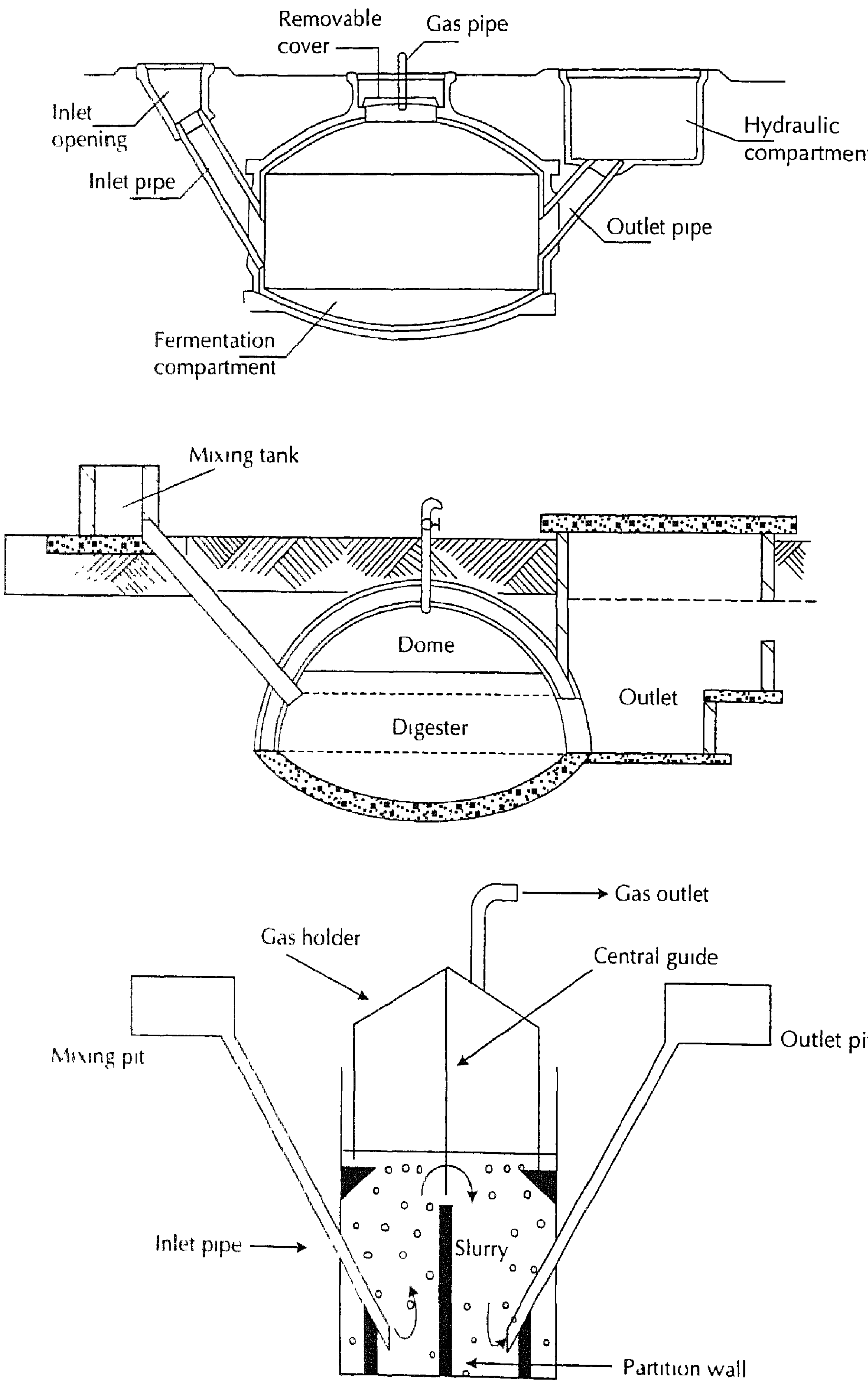


Figure 1. Small-scale biogas digesters; **a** Fixed-dome digester (Chinese); **b** Deenbandhu model (Indian); **c** Floating drum model (Indian)

suitably adopted the technology, but the encouraging efforts made in the recent past in Nepal, which has a most difficult terrain and not very favourable climatic conditions, have paid dividends in terms of installing over 25 000 biogas units, and Nepal is presently adding 10 000 units every year In fact, Nepal has added a new feather in its cap by promoting private biogas construction companies and farmers' participation. Thus, Nepal's programme should encourage many other developing countries to overcome the shock of past failures and start making rapid progress from now onwards.

It would not be wrong to conclude that Asian countries are the leaders in applying small-scale biogas technologies for the production of energy as well as enriched manure. When due care is taken in motivating and training all the stakeholders, including women users, and also in maximizing the economic returns, besides social benefits, by ensuring supply of quality gas appliances and proper use of manure for value-added products, biogas technology would definitely prosper.

With the increase in the foodgrain production, the stock of crop residues is expected to grow. While most of the residues would continue to be fed to animals, a sizeable quantity could be available for use as fuel material. In fact, in China, paddy straw is already being used along with pig manure and human waste in biogas units However, the rate of production of biogas from crop residues needs to be enhanced, possibly by microbial manipulation, to improve the economic viability of the technology In this direction, lignin and cellulose-degrading bacteria have been selected and genetically improved at the Tata Energy Research Institute (TERI), New Delhi, with the support of MNES. A consortia of such improved bacteria, when used with 50% replacement of cattle dung by paddy straw in a small-sized fixed dome biogas plant, have given encouraging results from the point of view of enhanced gas yield with minimum operational problems (Figure 2)

High-rate reactors

In recent years, with increasing environmental awareness, the Asian countries have also shown an interest towards high-rate anaerobic reactors for the production of biogas from agro-industrial effluents with the aim of recovering energy and remediating pollutants. In India, more than 60 alcohol distilleries have started using the biomethanation process in combination with some other secondary treatment to reduce the biological oxygen demand (BOD) and chemical oxygen demand (COD) to an acceptable level. The Indian Renewable Energy Development Agency (IREDA), which is the financing arm of MNES, has been providing loans for this activity since 1987/88 In view of its economic viability, the recent Asian Development Bank's Appraisal Mission has recommended a loan of US $20 million to IREDA exclusively for disbursement on biomethanation projects.

While most of these industries have gone in for some foreign technology (Table 1), the indigenously developed technology, particularly at the Daurala Sugar Works in the Meerut district, Uttar Pradesh, India, with the R & D collaboration and support of MNES, has given equal, if not better, results (Table 2) A flow diagram of the diphasic biomethanation process in use at Daurala Sugar Works is given in Figure 3

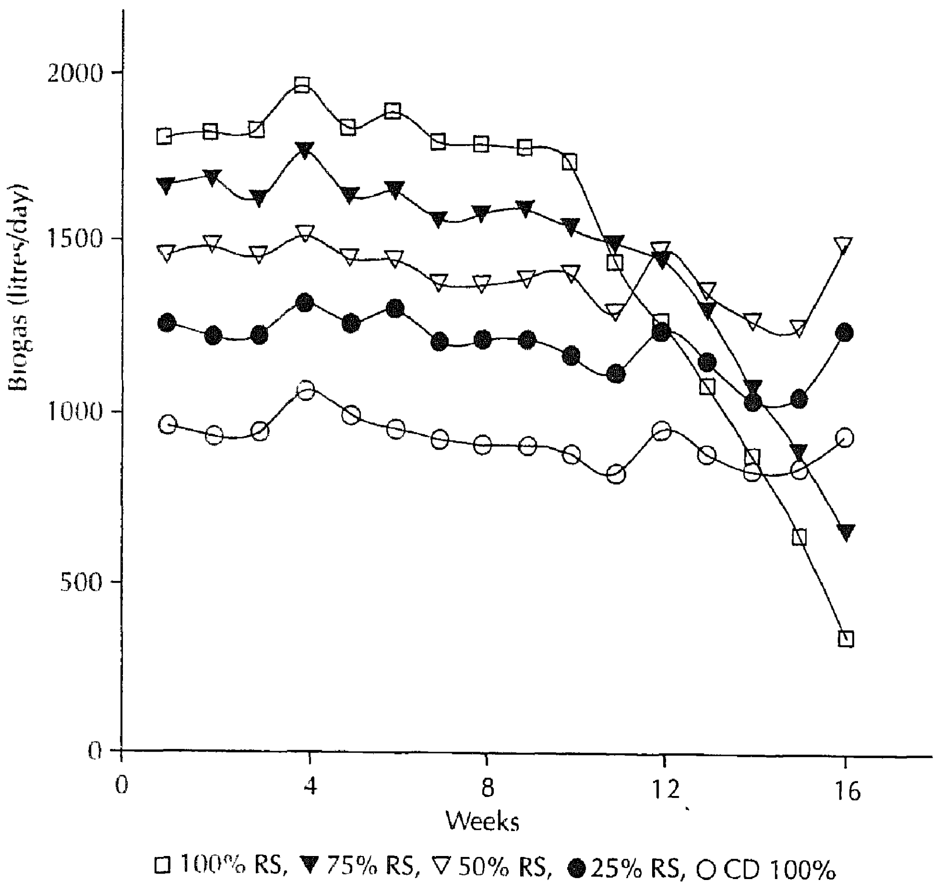


Figure 2. Biogas production from rice straw in a 1 m³ *Deenbandhu* model plant at various substitutions when improved bacterial consortia are used (Courtesy TERI)

TABLE 1
Technology collaboration with foreign companies under IREDA-funded biomethanation projects.

Technology	Country	Number of projects
SGN	France	5
Degrement	France	9
Biotim, MV	Belgium	7
ADI-BVF	Canada	3
Sulzer Bros	Switzerland	8
Paques BV	The Netherlands	4
Bacardi	USA	7
Dorr Oliver	USA	2
Lurgi, GmbH	Germany	2
Aqua Technos	Thailand	3
Indigenous	India	7
Total	—	57

TABLE 2
Performance highlights of the biomethanation plant capacity of 1600–1650 m^3 effluent/day in use at Daurala Sugar Works

Parameters	Performance
BOD	83–85% reduction
COD	67–70% reduction
COD loading	9–11 kg/m^3/day
Total retention period (acid + methane phase)	11–12 days
Gas production rate	32–35 m^3/m^3 of effluent
Biogas composition	
Methane	60–65% v/v
H_2S	Less than 0 5% v/v

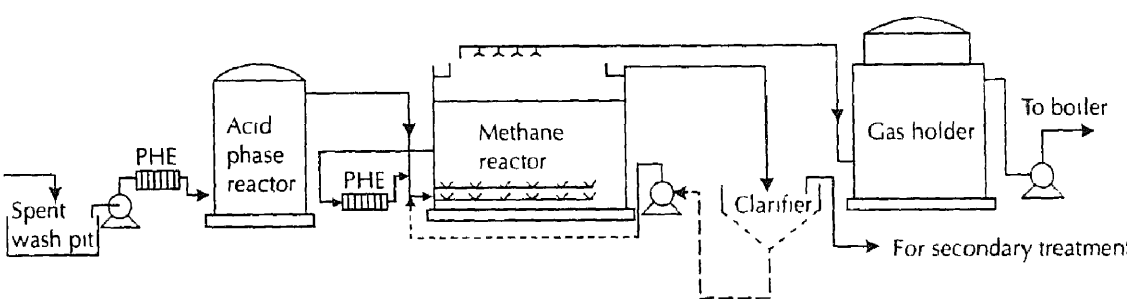


Figure 3. The diphasic biomethanation process at the Daurala Sugar Works

Sewage treatment with energy recovery

The Ministry of Environment and Forests have been supporting sewage treatment projects, with energy recovery wherever feasible, with a view to control the pollution of rivers. In all, five projects based on the upflow anaerobic sludge blanket (UASB) process have been in use at Allahabad, Kanpur, Mirzapur, and Varanasi, and four more such projects are under implementation.

Municipal and other solid wastes treatment

A Global Environment Facility assisted project titled 'Development of high rate biomethanation process as a means of reducing greenhouse gas emissions' is being implemented mainly to take up pilot demonstration projects based on municipal solid wastes, slaughter house wastes, vegetable market wastes, etc. Some of the state governments have taken initiatives in announcing conducive policy packages to provide garbage free of cost, land at nominal lease fees on a long-term basis, and also a power purchase agreement at a remunerative price. These efforts are expected to attract private sector participation and foreign investment.

Conclusions

Developing countries like China, India, and Nepal have widely applied small-scale biomethanation technologies for production of energy to meet cooking, heating, and lighting fuel requirements, and to supplement chemical fertilizers as well, besides harnessing several social benefits. However, the benefits at the national level in terms of saving of forests, improving soil productivity, reducing soil erosion, improving sanitation, addressing gender issues, etc., do not make the technology financially viable to individual households to attract private investment. Therefore, the national government's initiatives are essential even to promote these simple and locally built low-cost units.

In the case of high-rate biomethanation reactors, while their economic viability has been well established in Europe and the US, the developing countries would require not only foreign technology but also foreign investment. Simultaneously, more R & D has to be carried out to fine tune the designs to suit local conditions and to reduce the capital costs without compromising with environmental standards Further promotion of biomethanation technology in the treatment of sewage, municipal solid wastes, and other organic wastes is required to be integrated with the national as well as global environmental policies.

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UTILIZATION OF BIOMASS FROM MUNICIPAL SOLID WASTES FOR ENERGY RECOVERY, RECYCLING, AND DISPOSAL

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Introduction

From time immemorial, human beings have utilized the resources of the earth to support themselves. In early times, the needs were less and resources a plenty as the population was much less, and, consequently, wastes were not a significant problem Waste is a result of human activities from the dawn of civilization, which has become more prominent during and after the Industrial Revolution, and, today, the accumulation of wastes has become a consequence of life in an industrialized society (Sushil 1980; 1984, 1989).

The rapid increase in the density of population in selected areas as a result of urbanization and industrialization is making the collection, treatment, and disposal of waste an insurmountable problem, with serious sociological, ecological, and economic implications. The limited capability of nature to process the waste on its own poses ecological constraints against which the technological and spatial features of manmade processes in various spheres of activity must be designed. This aspect is gaining importance day by day. A sustained effort is, however, needed to restore the socio-ecological balance of nature in order to optimally harness the available resources. It is, therefore, imperative to design the waste management systems keeping in view technological, ecological, sociological, and economic aspects.

The inefficient and improper methods of waste management, particularly in developing countries like India (Vrat 1979) are creating pollution problems in the air, water resources, and land which are interfering with community life and development. An important feature of waste is its multiplicity characteristic, i e., uncontrolled or ill-managed waste leads to the creation of more waste, and the failure to salvage and reuse the waste results in the avoidable depletion of natural resources.

From the total resources available within a fixed time frame, a fraction is consumed, a fraction is wasted, and the remainder is a reserve. Consequently, the major objective of waste management is to minimize the fraction that is wasted.

Naturally, social costs are also incurred for effective waste management, and, therefore, it is essential to carry out a social cost-benefit analysis prior to the implementation of waste management systems. From the above discussion, it is clear that waste management is associated with the identification, reduction, storage, collection, transfer and transport, re-use and recycling, and processing and disposal of waste, keeping in view health, economics, engineering, conservation, aesthetics, and all other environmental conditions involved in the complete spectrum of the solution to the problem of waste. However, the present study on waste management is restricted to management of municipal solid wastes (MSW).

Further, as a consequence of the increasing population of the world, handling and utilization of MSW is becoming a problem to almost every country on the globe. The future scenario regarding MSW looks bleak with more and more of it being generated as economies of many countries modernize. Therefore, it is of utmost importance to understand and decide as to how the MSW is to be handled, disposed, or utilized economically, and with minimum environmental degradation.

Sectors in waste management systems

In most developed countries, and also in some developing countries, there are basically six sectors to which municipal solid waste can be recycled/disposed of. These are:

- biodegradable recycling;
- non-biodegradable recycling;
- composting;
- incineration;
- pyrolysis; and
- landfills.

The sectors of waste management, waste generation, and consumption of outputs of waste management are shown schematically in Figure 1.

Recycling of waste

Recycling of waste involves both biodegradable and non-biodegradable recycling of salvable waste Some broad guidelines that could be followed to dispose of salvable waste include

- analysis of the feasibility of recycling to be analysed;
- use of waste to produce by-products;
- evaluate feasibility of selling waste/scrap as raw material to other factories/agencies dealers; and
- identify proper processing techniques to generate useful products from the waste.

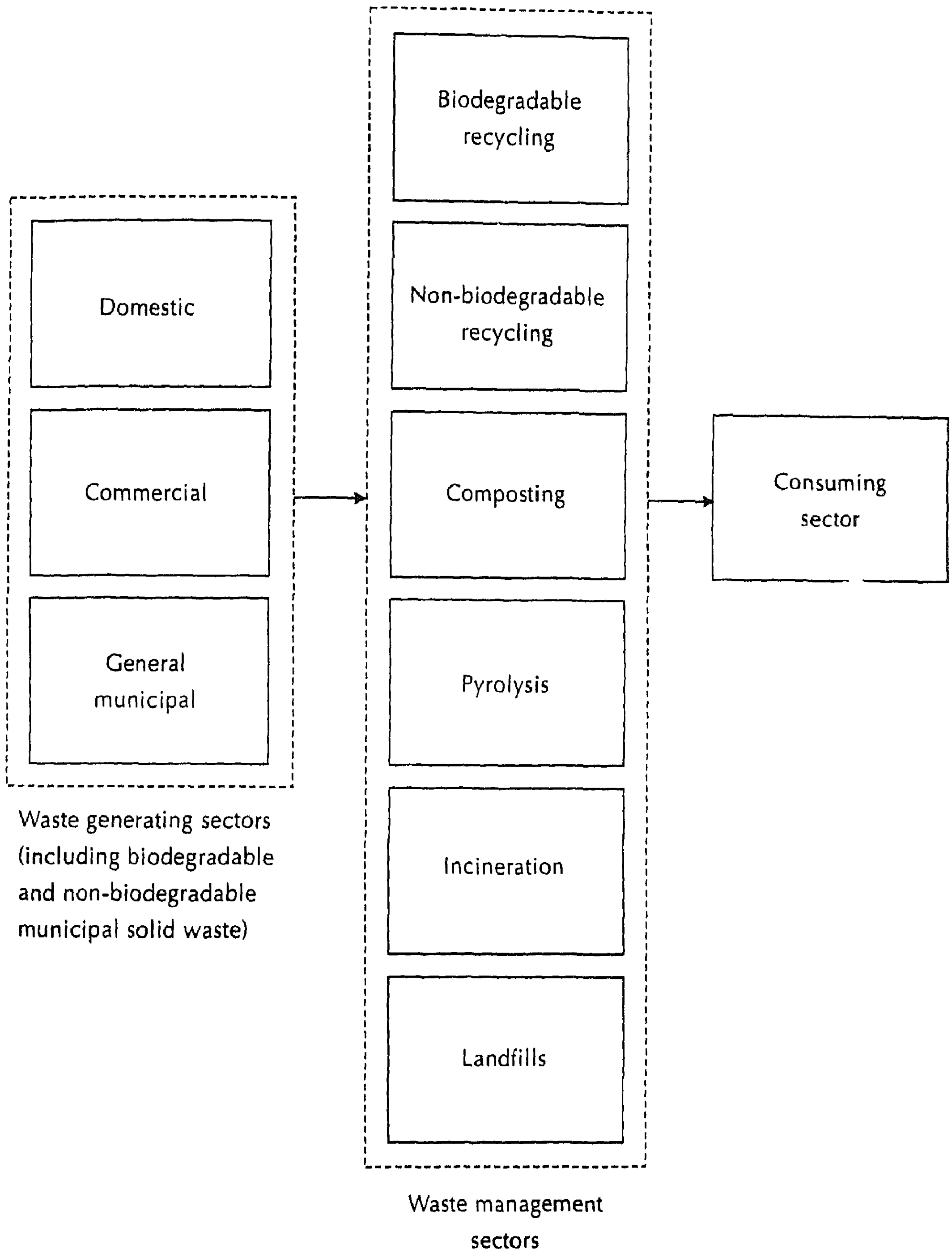


Figure 1. Schematic diagram of the overall waste management system

However, recycling is only now becoming important in developed countries. In nature, 98% of everything is recycled (Bellamy 1993). Nothing goes to waste, and that which goes into long-term storage helps produce the oxygen without which life, as we know it, would soon grind to a halt. Accordingly everything must become recyclable, and thus, ultimately world waste will become extinct. This is not going to be possible until alternative energy

sources are available, as some recycling procedures are highly energy intensive. These days, plastic recycling is becoming important as various European countries plan to recycle a large quantity of plastics primarily used in packaging. For example, Germany planned to recycle two-thirds of all sales packaging by 1995 comprising primarily of plastics. France set a target of 75% recycled material to be achieved by 2003 AD, including incineration with energy recovery. The European Commission has proposed a 60% recycling of packaging within five years with a minimum of 30% for any single material (Snow 1994).

However, waste minimization is more important than recycling for sustainable development (Kersey 1994). Skinner (1994) feels that recycling or reusing as much waste as possible is important. A major recycling impediment is the question of continued viability and availability of secondary materials markets.

It is important to understand that separation of materials from the solid waste stream by itself does not constitute recycling, which occurs only when these materials are incorporated/processed into products that enter the commercial arena (Skinner 1994).

To analyse the economic feasibility of recycling, one must consider the price received for the recycled material, the solid waste collection and disposal costs avoided, and the cost of separation, collection, and processing the separated materials. While doing the above cost comparisons, it is essential to consider all environmental costs and benefits. Further, the benefits to future generations in terms of natural resources consumed or landfill space minimized must be considered.

Therefore, it is essential that waste reduction activities and recycling must be undertaken simultaneously, as, along with recycling, waste reduction also provides excellent returns on investment. Brierley (1993) also indicates that waste minimization at source also leads to payback. Sushil (1990) has discussed recycling of waste as an aid to resource conservation

Based on the above consideration, the material–energy flow modules of both biodegradable recycling and non-biodegradable recycling are shown in Figures 2 and 3, respectively, indicating the flow of materials and the waste generation and useful product streams. Recycling has also been analysed in a systems dynamic framework (Mashayekhi 1993).

The biodegradable recycling sector has three major inputs of the waste generated, namely, domestic biodegradable recyclable waste, commercial biodegradable waste, and general municipal biodegradable recyclable waste. These are mixed and processed using raw materials and energy to produce useful products. For example, while utilizing paper waste, after biodegradable recycling and chemical treatment, high quality paper could be produced after the necessary processing in the paper mill. The effluent generated is the liquid pollutant, the digested sludge is the solid pollutant, and the gases generated from the boilers and vapours of the chemicals lead to gaseous pollutants as shown in Figure 2. However, non-biodegradable recycling involves, besides other things, processing of metallic scrap and includes primarily waste of such types from domestic, commercial, and general municipal sources. It also includes glass bottles waste, which is processed to produce glass bottles after processing and supply of energy. The effluent and cooling tower blowdowns result in liquid pollution, slag and mud result in solid pollution, gases from the boiler and the furnace, fumes from the chemicals used in treatment of the scrap leads to air pollution, as shown in Figure 3.

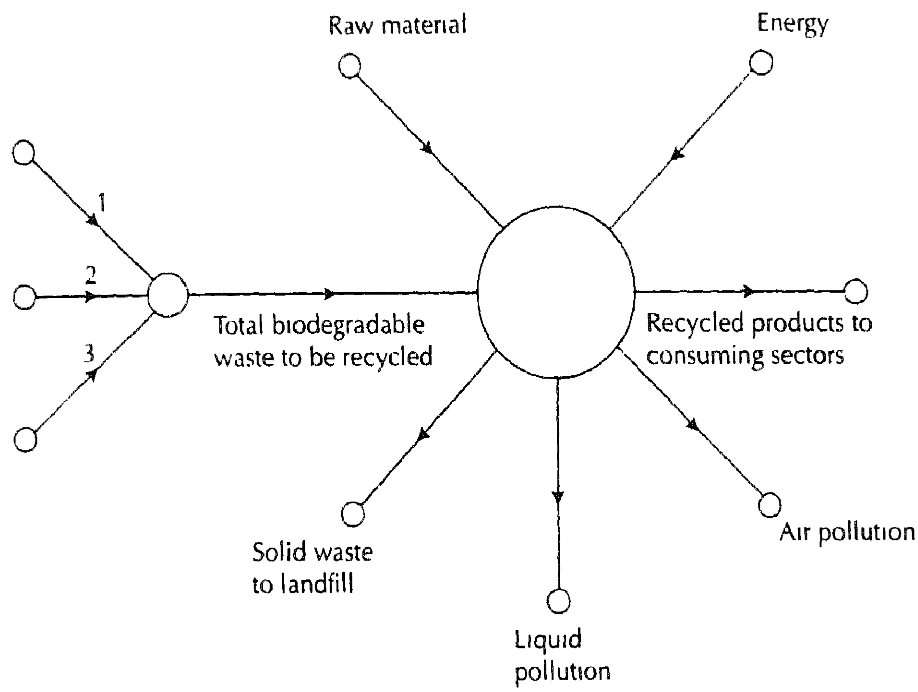


Figure 2. Material–energy flow models: biodegradable recycling; 1: domestic; 2: commercial; 3: municipal

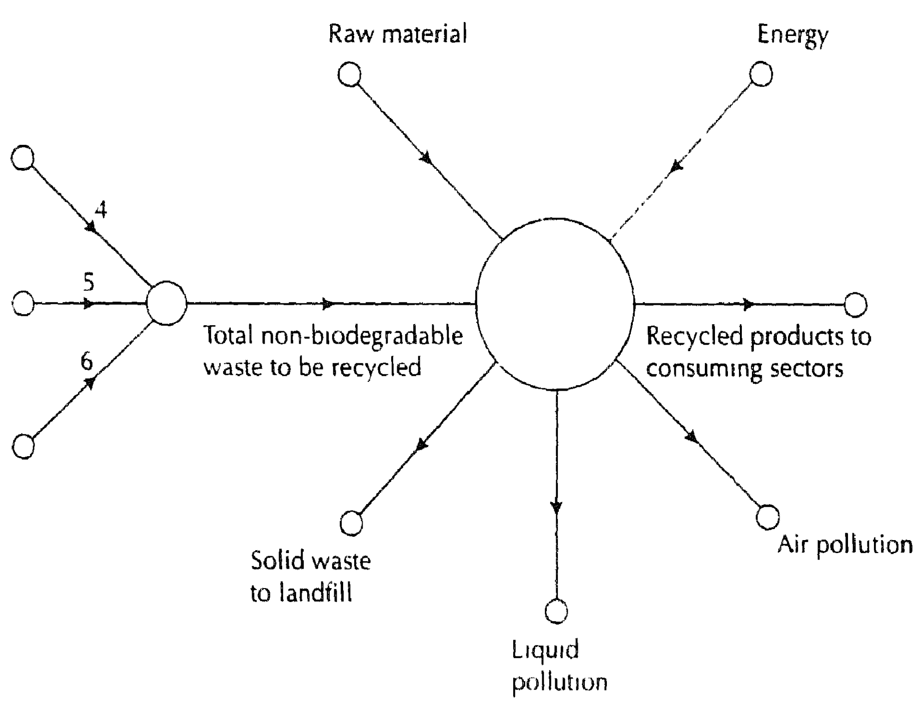


Figure 3. Material–energy flow model: non-biodegradable recycling; 4: domestic; 5: commercial; 6: general municipal

Composting

Composting of solid waste may be defined as the biochemical stabilization of these organic materials to a humus-like substance through scientifically producing and controlling an optimum environment for the process. It is the application of controlled methods that differentiates it from natural rotting, putrification, or other forms of decomposition. Composting is generally classified on the following basis:

- usage of oxygen, namely, aerobic (oxygen is used); and anaerobic (oxygen is not used)
- temperature: 20–35 °C mesophilic (ambient temperature); and
- the technological option:
- open window: low heap of organic matter; and
- mechanical or enclosed.

There are three basic methods of carrying out successful composting of botanical and putrescible materials. The first and most common method because of its basic simplicity and generally low cost is open windrowing.

The second method varies depending on the investment and sophistication of control in static aerated pile composting. This can be done either in the open, in enclosed space, or in specially constructed tunnel chambers.

The third method is anaerobic digestion followed by aerobic composting of the residues. This method is now being widely used in the UK.

Finally, the compost is bagged in order to facilitate ease of handling; this is essential if retail selling is to be carried out. Bags should be carefully designed as they will have a great impact upon the saleability of the contents. In order to improve the quality of the compost, source separation of municipal solid waste is essential.

Composting in Europe and the US is continuing to develop successfully, and, in the UK, it is being successfully developed as a method of disposal despite the known low costs associated with conventional landfills. It also has potential in India. It has been used for a long time in rural areas, but there is a need to make the people aware of its benefits and for a rigorous organized effort. Comprehensive data on the quantity of waste composted in the country are not available.

The flow model of composting process is given in Figure 4. Composting includes biodegradable waste from domestic, commercial, and general municipal sources which is mixed and processed using bacteria and energy in the presence or absence of air to produce fertilizer/manure used for horticulture/gardening purposes. The percolation of the moisture into the ground leads to liquid pollution; the uncomposted waste leads to solid pollution, the putrification of waste leads to air pollution and odour formation.

Composting, as discussed above, could also be considered as a waste disposal recycling technique.

Incineration

It is an important method for waste disposal as incineration involves the thermal processing of waste which results in the reduction in volume and generation of energy and by-products

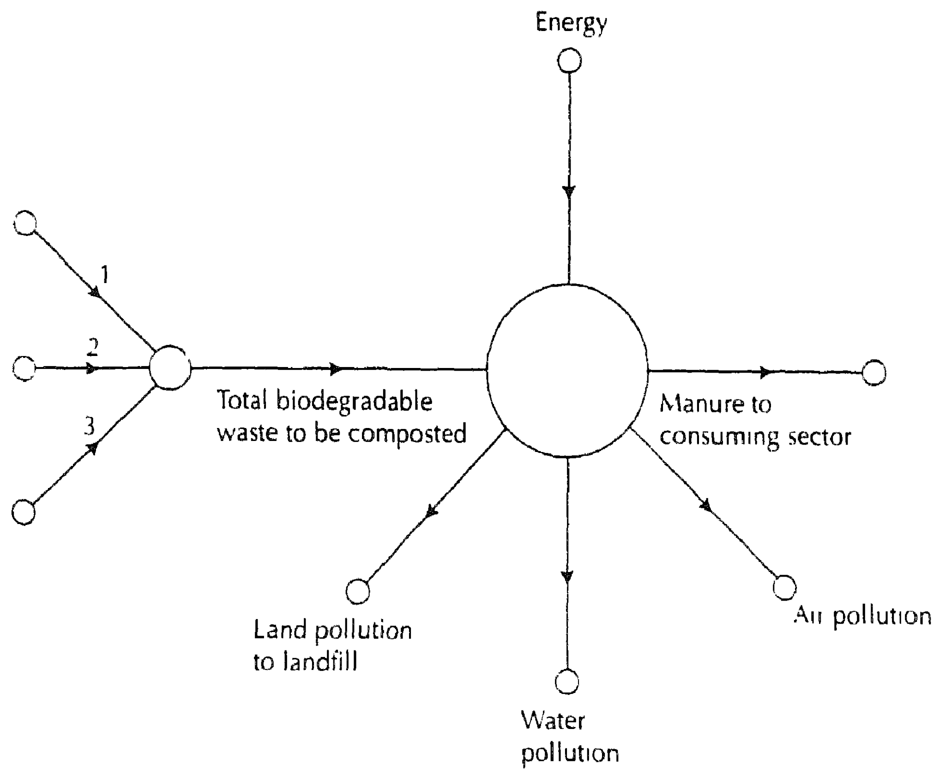


Figure 4. Material–energy flow model: composting; 1: domestic; 2: commercial; 3: general municipal

Incineration is defined as high-temperature oxidation of the organic and toxic compounds present in gaseous wastes and is employed to destroy the offensive effluents and odours by converting them into harmless gases, i.e., CO_2 and water vapour. Incineration results in about 80–90% volume reduction and results in the generation of energy

It is essential to study the following points before designing incineration systems:

- combustion characteristics of solid waste;
- weight and volume reduction ratio;
- heating/calorific value of solid waste;
- air requirements for combustion; and
- trace constituents to control air pollution caused by incineration.

According to Mashayekhi (1993), the incineration sector processes solid waste to produce energy. Incineration produces ash, which must be dumped in the landfills. According to Porteous (1993), incineration complements other forms of treatment, rather than being a complete alternative. Incineration is a long established waste management option and schematic incineration of household waste was pioneered in the UK in the late 19th century (Santen 1993). However, it is less cost-effective than recycling and other waste minimization alternatives, and is more expensive than even other waste disposal options, including landfilling. Incineration as a waste management option has been analysed (Bellamy 1993). Skinner (1994) integrates solid waste management along with incineration.

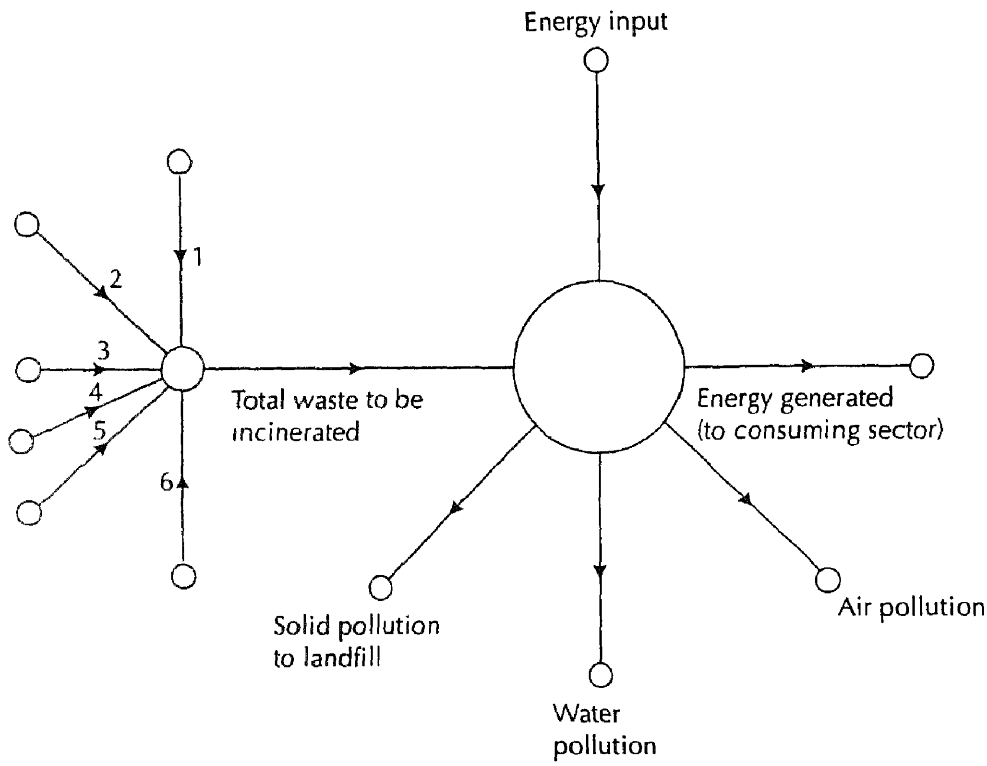


Figure 5. Material–energy flow model: incineration; Biodegradable MSW – 1: domestic; 2: commercial; 3: general municipal; Non-biodegradable MSW – 4: domestic; 5: commercial; 6: general municipal

A material–energy flow model of incineration is shown in Figure 5, depicting the flow of the material wastes involved. In the incineration process, all types of waste from domestic, commercial, and general municipal sources are mixed, of both the non-biodegradable and the biodegradable type. It is processed utilizing energy leading to the production of more energy depending upon the composition of waste, which could be utilized to produce power. The char generated leads to solid pollution which is ultimately disposed of into the landfill. The gases generated during incineration lead to air pollution. The condensed water vapour, along with dust, and the intermingling of the gases with the water vapour formed during the incineration, creates liquid pollution.

Pyrolysis

Pyrolysis is defined as the destructive distillation or the thermal decomposition of wastes in an inert atmosphere producing a mixture of gaseous products, tar, methanol, and other organic compounds, water-insoluble oils, an aqueous solution of acetic acid, and a solid residue, i.e., char

According to Srivastava, Jalan (1994), and Srivastava, Sushil, Jalan (1994; 1995) the various components produced in pyrolysis are [percentage of weight (approximately)]:

- gaseous products 25%;

- char 17–25%; and
- liquid phase 20–80%.

Further, pyrolysis has other advantages which are not present in other waste management sectors. These are listed below.

- Production of energy in a convenient usable form.
- Much less air pollution as the process is carried out in an inert atmosphere.
- Recovery of valuable chemicals.
- Reclamation of metallic components.

Therefore, pyrolysis is considered to be an industrial process rather than a waste management process. The process of pyrolysis has been studied by Bradbury, Sakai, Shafizadeh (1979); Brunner, Roberts (1980), Jegers, Klein (1985), Koufpanos *et al* (1991); Srivastava, Jalan (1994); and Srivastava, Sushil, Jalan (1994, 1995). However, very little work has been done to integrate pyrolysis along with waste management in order to analyse its importance in its entirety

A material–energy flow model of pyrolysis as a waste management sector is given in Figure 6 The processing with the supply of energy takes place in the absence of air resulting in formation of solids (charcoal), liquids, and gases, which could be used as fuel

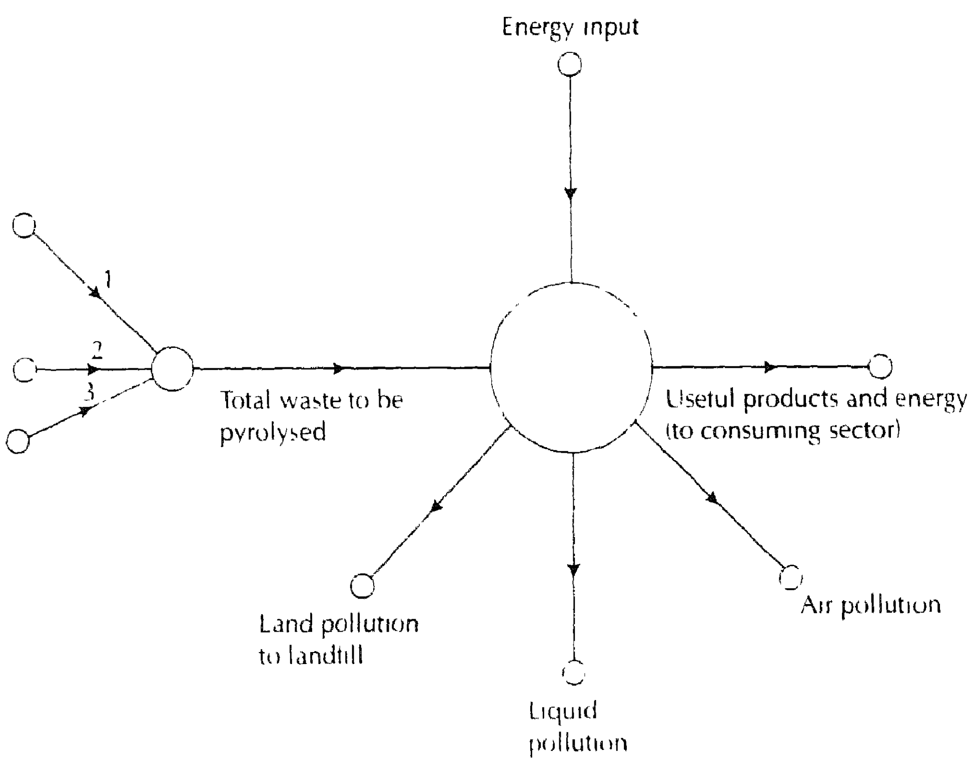


Figure 6. Material–energy flow model: pyrolysis; 1: domestic; 2: commercial; 3: general municipal

for industrial purposes. The ash generated leads to soil pollution. The emissions from the pyrolysis process create air pollution. Liquid pollution is caused due to the condensation of water vapour which may react with some of the volatile products, resulting in water pollution.

Landfills

Besides acting as a disposal site for various types of waste, landfills are also considered as an ultimate disposal waste management sector for those solid wastes that are of no use and remain even after recycling, processing, etc.

Sanitary landfills have been proclaimed for some time as a low-cost and safe way of disposing of MSW. Wilson (1993) has discussed the development of landfills in historical perspective in Europe and highlighted the policy and practice with a simple landfill step ladder. According to Bellamy (1993), landfills are one of the five major methods of waste disposal.

Some of the advantages of the sanitary landfills are given below.

- The initial investment is comparatively low. However, with land prices increasing regularly, it is sometimes difficult to acquire adequate land at reasonable prices.
- A sanitary landfill can receive all types of waste eliminating the necessity of separate collection.
- It is flexible with reference to the quantity and composition of waste being disposed.
- It helps in the reclamation of low-lying areas.

The above advantages become important, provided a proper site is selected for the landfilling operations. The important factors relevant in site selection are :

- social and political aspects of land use;
- climate topography and natural features;
- cost and haulage distance;
- public acceptance;
- noise, dust, and air pollution.

The common methods of landfilling are the area method, the trench method, and the depression method. Accumulated solid waste in landfills generate pollution in the environment (Mashayekhi 1993). However, according to Skinner (1994), landfill technology has advanced very rapidly over the past decade. Today's state-of-the-art landfills are equipped with leachate collection systems, liner systems, systems for control of landfill gas, groundwater monitoring, closure and post-closure care, and much more The objective is to ensure that landfilling is performed in a manner that greatly reduces the change of environmental degradation, and, also, that any degradation that occurs is quickly detected and remediated.

However, in the US, the number of landfills continues to decrease. Two main consequences arise

- communities face longer transport distances to deliver their solid waste to disposal sites; and
- several large facilities, designed to serve a limited number of communities for a given number of years, are seeing their lifespans drastically foreshortened by the influx of waste from outside their service areas.

Crawford, Smith (1985) have dealt in detail with all aspects of landfill technology, and Harris, Knox, Walker (1994) have developed a strategy for the development of sustainable landfill design including leachate treatment by the development of highly efficient bioreactor landfills for mixed wastes, with high leaching rates.

A material–energy flow model of a landfill is shown in Figure 7. All types of wastes from all sources are mixed and fed to landfills, which are compressed and left below the ground after they are covered to produce methane gas which could be used to produce electrical power or supplied to homes as fuel. In many landfills, a landfill liner of a thermosetting plastic is used in order to reduce the percolation of leachate which is produced in landfills. However, there is the leakage of the leachate from the tips of the landfill liner resulting in liquid pollution. The non-converted solid waste leads to land pollution The generation of gases other than methane during the process of gas extraction from the landfill, which is

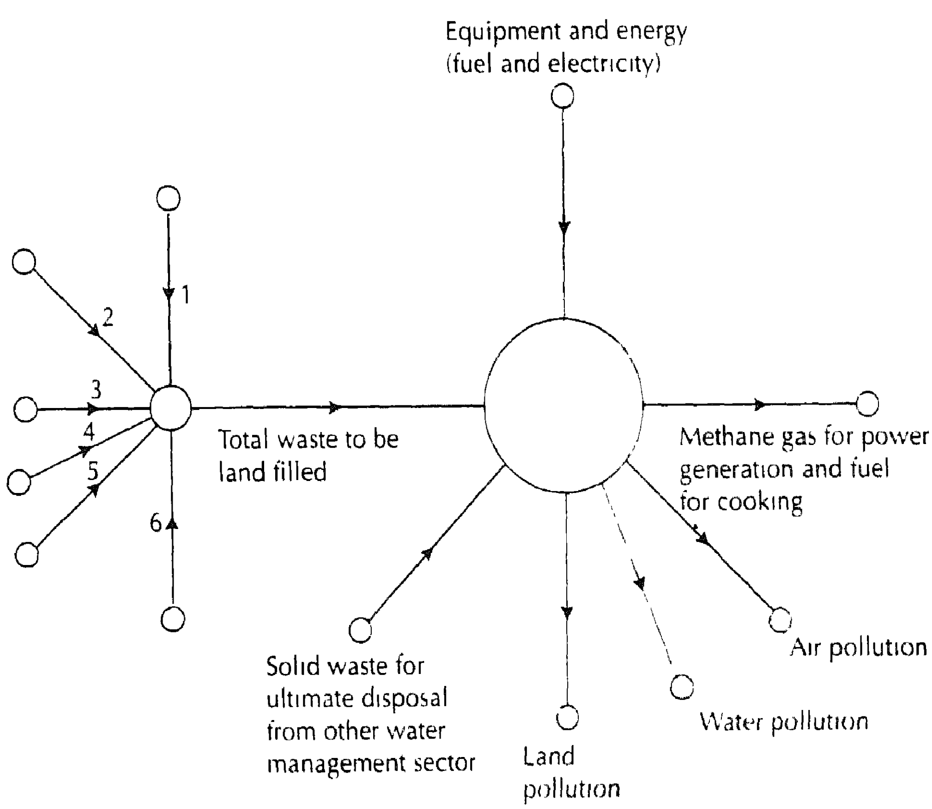


Figure 7. Material–energy flow model: landfills; Biodegradable MSW – 1: domestic; 2: commercial; 3: general municipal; Non-biodegradable MSW – 4: domestic; 5: commercial; 6: general municipal

due to the putrification of waste, leads to air pollution. Methane from landfills is used widely in the UK and other European countries to generate power, and also as a fuel for heating of homes and for cooking

Considering the above, landfilling is perhaps the most important waste disposal method as it also acts as an ultimate disposal to finally process the solid waste.

Development of modelling methodology

The modelling methodology is selected based on the conceptualization of the problem being studied and matching the attributes of the problem with the system-based techniques. A Physical System Theory (PST) framework, integrated with system dynamics (SD), is proposed as an appropriate modelling methodology for the waste management problem for supporting multiple levels of decision-making. PST provides a modelling tool for discrete physical flow systems with finite interfaces, which are prevalent in waste management SD, however, provides a framework for studying the system from a dynamic stand-point and with its thrust on the learning paradigm, it would be able to provide more insight into the operation of the system. A brief review of PST and SD is presented, and its integration mechanism along with the advantages obtained by the synergistic approach, are highlighted

Flexible systems methodology: an overview

Systems methodologies have been developed as a response to the ever-increasing complexity of systems and the increasing need to adopt system-based methodologies for solving problems with a thrust on implementation in an end-user environment. The task of designing or selecting methodology for a particular problem-situation is becoming more difficult with an ever-increasing choice of techniques. The integration of qualitative and quantitative tools is emerging very rapidly to cater to the diverse requirements of management-related problems in general, and MSW management in particular. Keeping the above in view, Sushil (1994a) suggested a flexible systems methodology, which is built on a spectral, integrative, and innovative paradigm. It tries to resolve the end of continuum paradoxes as it is based on a spectral paradigm, treating all the system-based methodologies on a continuum from hard to soft, and also all problem situations from well structured to unstructured

For example, PST is hard in its design, while Delphi, Scenario Building, etc , are soft. However, SD is, somewhere, in the middle of the hard and soft continuum. The flexibility in using the SD methodology has been presented in Sushil (1993)

The flexible systems methodology involves conceptualization of the problem, fuzzy clustering of the problem and system-based techniques, matching of attributes, and selection and integration of techniques which are most appropriate for both the problem and the solution This approach has been followed for the selection of the modelling

methodology in the present study as problems in real life being considered in this paper are not clustered on the ends of the continuum. They lie on the whole continuum, and, more realistically, on the middle part than the ends, having some parts structured and some parts unstructured.

Problem conceptualization

The problem area has been conceptualized in terms of various attributes and its characteristics as presented in Table 1

From the above conceptualization, it is clear that the waste management system has physical flows of items through discrete components with well-defined finite interfaces. It also involves some managerial planning for high-level tactical decisions in a multi-location system. In real life, the system of waste management is dynamic, interacting with internal as well as external factors.

A fuzzy clustering of the attributes identified above is obtained utilizing the flexible systems approach by considering various attributes of problem of waste management.

In the system proposed in this study, the problem consists of a mix of operating to strategic problem areas and the decision process involves unitary to pluralistic decision making. Further, the problem situation indicates a mixed character of the operating system and the policy decision system indicating that the problem would be somewhere in between the well-structured and unstructured problem.

The problem conceptualization indicates that the requirement is for a generalized flow modelling methodology which is capable of covering the entire spectrum of decisions as well as meet the requirements of multiple levels of decisions. Further, the model must be flexible so that variables could be incorporated in order to facilitate analysis. In view of the requirements of the problems as mapped on various attributes, two flow modelling methodologies, namely, PST and SD have been identified to have a high possibility of application for analysing waste management systems.

TABLE 1
Conceptualization of MSW management problems

Attributes	Characteristics
Nature	Physical flow of waste through various transportation–transformation processes
Structure	Multiple location; flow structure
Situation-specific characteristics	Mix of stochastic (type of waste) and deterministic processes; reasonable steady state
Nature of outcome desired	To support decision-making; learning about the waste management systems; facilitate policy analysis
People involved	Not well-versed with quantitative models good in judgement; wide experience
Decision environment	Bureaucratic; stress on empirical models; rules of the thumb

Matching attributes with system techniques

The details of matching of attributes of PST and SD methodologies are given in Table 2.

From the above, it is clear that as a flow modelling technique, PST facilitates modelling and analysis of physical flow systems with discrete interfaces having a well-defined structure. PST models two variables, namely, the physical flow and the associated cost or energy inputs. The system equations are written as a set of algebraic linear equations and an analytical solution is possible. Application of this methodology requires a well-structured system and is very well suited for operational decisions.

However, in SD, the flow of information is modelled along with the physical flow, the emphasis being on storages and levels. It is, therefore, used for modelling semi-structured and unstructured problems with focus on policy analysis. SD, according to Sushil (1993), is based on the principle that the behaviour of a system is due to its structure and policies. This method permits experimentation with multiple policies and an analysis of the effect of these on the system.

Selection and integration

Matching of the PST and SD attributes with the problem attributes shows that neither of the methodologies by themselves is able to meet the entire set of problem attributes. It is found that PST and SD exhibit complementary attributes in many of the areas and an integration of the PST methodology under a SD framework would meet the problem requirements. Therefore, in order to understand the waste management system, it is essential to integrate the PST and SD methodology and evolve a suitable approach. In this system SD is amalgamated with the PST framework as shown in Figure 8.

As the waste management problem is analysed using the above methodologies, there is a dynamic shift in the attributes of the problem. The application of the proposed method-

TABLE 2
Matching of problem and technique attributes

Problem attributes	PST attributes	SD attributes
Physical flow of waste	Physical flow model with material and cost	Flow model of physical flows and feedback of information in levels and storage
Multiple levels involving structured and semi-structured decision-making	Structured with focus on deterministic decisions	Unstructured and semi-structured areas with focus on policy analysis
Dynamic system	Analytical solution	Dynamic study through simulation
Transparent modelling and graphical representation scheme	Transparent modelling methodology with minimum ambiguity and abstraction	Relatively involved graphical representation
Solution procedure	Algebraic linear equations can be solved manually and easily	Special software packages like 'DYNAMO' required

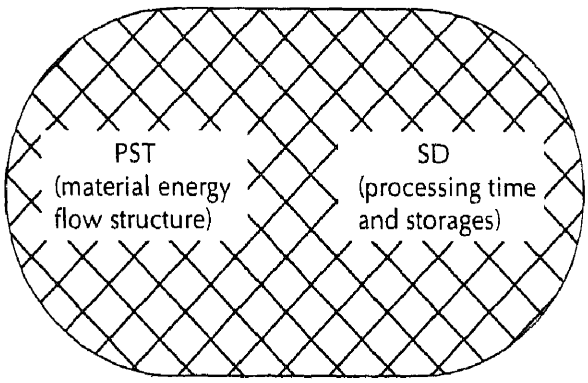


Figure 8. Amalgamation of PST and SD

ology using both PST and SD can be done flexibly depending upon the cognitive burden and expertise available.

The strengths and limitations of the proposed flexible systems methodology for the waste management problem are explained by Sushil (1994a) in detail. According to him, the limitations can be overcome by developing a suitable 'expert system' for this purpose.

The flexibility being proposed in this study is systemic flexibility having major attributes of spectral, integrative, interactive, innovative, and fuzziness characteristics indicating a trend towards flexibility in waste management.

The continuum approach to waste management could also involve treating the various waste management sectors ranging from recycling to the ultimate disposal in landfills along a continuum with other sectors falling in the line of the continuum as shown in Figure 9.

Here, the real situation is considered to be dynamic as the composition of waste changes regularly and ambiguously. Therefore, it is proposed to consider a spectrum and attempt to integrate, interact, interplay, or innovate capturing its fuzziness. Therefore, for managing waste, the flexible systems management is a natural process (Sushil 1994b).

Model development using the physical system theory

PST originated in the field of electrical engineering for the analysis of complex electrical networks and circuits. PST is based on the graph theoretic approach which has flow vari-

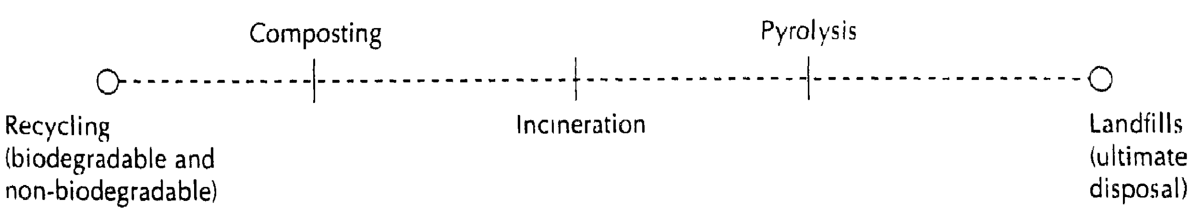


Figure 9. The continuum approach to waste management

ables (quantity input/output to the system) and the costs involved/incurred in the waste management system.

Keeping the above in view, it is possible to utilize the PST approach to waste management. Sushil (1993) utilized this type of analysis for waste management along with goal programming for national planning. Recent work (Sushil 1992; 1993) has thrown some light on the applicability of PST to various areas. Consequently, this work has been taken to utilize PST to many critical aspects of waste management, and, particularly to MSW management. As previously discussed, the three major waste-generating sectors as far as MSW is concerned, and which are being analysed in this paper, are: domestic waste, commercial waste, and municipal waste.

While domestic wastes are primarily generated in residential houses, commercial wastes include those from industrial and office complexes. Municipal waste is generated on roads, sidewalks, and pavements, in parks, etc., and is generally collected by the local authority of the area.

Each of the above type of wastes would ultimately be recycled or disposed of in one or more of the six waste management sectors detailed earlier.

Each waste management sector has basically three elements, i.e., waste input, output of a useful product/energy, and processing of waste, leading to further pollution of land, air, and water, as the case may be, as indicated in Figures 2 to 7.

The above concept can be depicted schematically in a generalized flow model (Figure 10) for any waste management sector.

In the present study, for all the waste management sectors, only one consumption sector is considered.

Based on the overall schematic diagram (Figure 1) of the waste management systems and the material–energy flow models (Figures 2 to 7), the cost and flow equations of each type of waste management sector are obtained. The parameters and variables involved are given below.

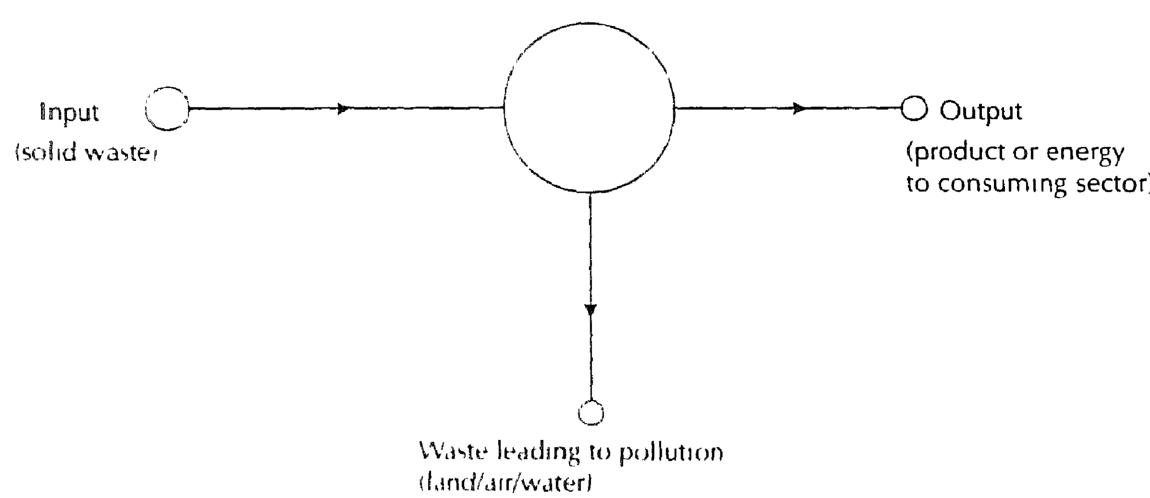


Figure 10. Generalized flow model of a waste management sector

Parameters

1 Technological coefficients for water, land, and air pollution are provided. The technological coefficient is the ratio of pollution generated per unit of waste input to the waste management sector.

2 The technological coefficient for domestic, commercial, and municipal wastes, which is based on the quantity of waste divided by the total quantity of waste input to the system for both biodegradable and non-biodegradable waste, is computed separately.

Exogenous variables

- Cost of processing the waste to produce a product/energy based on one of the six processing systems discussed earlier.
- Cost of handling biodegradable waste from the source to the composting site for domestic, commercial, and municipal wastes
- Cost of water, land, and air pollution respectively

Endogenous variables

The variables generated while executing the model include:

- the product/energy output from the waste management sectors model after accounting for waste sectors;
- the quantity of solid, liquid and air pollution generated; and
- the cost/unit of producing the output/product for the consuming sectors.

The above equations are a set of algebraic equations which are static in nature and can even be solved manually. It is suggested that one solves at least one set of equations manually in order to understand them physically before employing a suitable software package to solve the equations on a computer. The PST model is integrated subsequently utilizing SD.

Computer simulation in the SD framework

A special package known as DYNAMO has been utilized to solve the above type of equations in a systematic manner so that the flows and cost can be analysed independently Subsequently, SD has been incorporated by introducing levels and storages through DYNAMO.

Simulation on DYNAMO was done utilizing the cost and flow equations for each waste management sector by the characterization of the constant and auxiliary equations for each sector. Subsequently, SD was introduced by incorporating levels and storages in the model, which bring the processing time and storages in the system. The relationship of flow and state variables describes the dynamic nature of waste management system (Mashayekhi 1993). This approach is limited only to study the cost and flow analysis of the physical waste management system in a dynamic mode. This provides the basic model which can then be integrated with other policy issues as discussed (Mashayekhi 1993).

Conclusions

The above model could be used for allocation of waste to different waste management sectors, and could be analysed considering:

- source segregated waste;
- centrally segregated waste; and
- non-segregated waste

The PST model, integrated with SD, developed for waste management has universal applicability The input parameters for various conditions depending upon the country, location, and socio-economic characteristics could be altered. The model is simulated on DYNAMO to obtain values for various cost and flow variables which are utilized to ascertain allocation to various types of waste management sectors, considering various types of segregation methods by altering the flow to the waste management sectors.

The above model could be utilized for local planning of waste management facilities, provided efforts are made to obtain the parameters required in the model, most of which are accessible in developed and industrialized countries. Gradually, such information is also being made available for developing countries. Therefore, it is clear that PST along with SD could be applied to waste management in order to study its cause and effects on the waste management system and understand the dynamics of the entire process involved. PST integrated with SD is an excellent tool available to aid planners in the management of waste. Policies of the government and regulatory bodies, financial considerations, etc., can also be incorporated in the above model in an SD framework. The approach used for planning the waste management system can thus be carried out systematically and flexibly to enhance the effectiveness of these systems. Research work, to deal with the technical, managerial, and economic issues of managing waste using a flexible systems approach, is in an advanced stage to provide a comprehensive framework for developing more effective waste management systems.

References

Bellamy D. 1993. Waste watching *Wastes Management Proceedings*. pp 3–5.

Bradbury A, Sakai Y, Shafizadeh F 1979. A kinetic model for pyrolysis of cellulose. *Journal of Application Polym. Sciences* 23: 3271–3280.

Brierley M J 1993 Environmental objectives: going for gain not pain. pp 52–53. *Wastes Management*

Brunner P H, Roberts P V 1980 The significance of heating rate on char yield and char properties in the pyrolysis of cellulose *Carbon* 18. 217–224

Crawford J F, Smith P G 1985 *Landfill Technology*. London: Butterworths.

Harris R C, Knox K, Walker N 1994. Strategy for the development of sustainable landfill design. *IWM Proceedings*. pp. 26–29

Jegers H F, Klein M T. 1985. Primary and secondary lignin pyrolysis reaction pathways, *Ind. Enq. Chem. Process Des Dev* 24: 173–183.

Kersey J D. 1994. Sustainable development and wastes management pp 48–52 *Wastes Management.*

Koufopanos C A, Papayannakos N, Maschio G, Lucchesi A. 1991. Modelling of the pyrolysis of biomass particles: studies on kinetics, thermal, and heat transfer effects *Canadian Journal of Chemical Engineering* 69: 907–915.

Mashayekhi A N 1993. Transition in the New York state solid waste system. a dynamic analysis *System Dynamics Review* 9(1): 23–47.

Porteous A. 1993. The Incineration of Waste *Wastes Management.*

Santen A V. 1993. Incineration: its role in the UK waste strategy. pp. 18–23. *Waste Management Proceedings*

Skinner J. 1994. International progress in solid waste management pp 3–5 *IWM Proceedings*

Snow B. 1994. Overview of plastics recycling. *Wastes Management* 39 pp

Srivastava V K, Jalan R K. 1994 Prediction of concentration in the pyrolysis of biomass materials I. Part I *Journal of Energy Conversion & Management* 35(12) 1031–1040

Srivastava V K, Sushil R K, Jalan R K. 1994 Development of mathematical models for prediction of concentration in the pyrolysis of biomass materials. Presented at the Symposium on Advances in Chemical Engineering at Indian Institute of Chemical Technology, Hyderabad, India

Srivastava V K, Sushil R K, Jalan R K 1995 Prediction of concentration in the pyrolysis of biomass materials. Part II. Accepted for publication in the *Journal of Energy Conversion & Management.*

Sushil R K. 1980. Systems approach to waste management in India MTech Dissertation New Delhi. Indian Institute of Technology

Sushil R K 1984 Systems modeling of waste management in national planning. PhD Thesis. New Delhi: Indian Institute of Technology.

Sushil R K 1989. *Systems approach in national planning: a study in waste management* New Delhi: Anmol Publication

Sushil R K. 1990. Waste management. a systems perspective Special issue *Industrial Management and Data Systems* 90(5): 1–67

Sushil R K. 1992 Simplification of physical system theory in the modelling of manufacturing, organizational and other socio-economic system. *International Journal Systems Science* 23(4): 531–543.

Sushil R K 1993. *System dynamics – practical approach for managerial problems.* New Delhi Wiley Eastern Ltd.

Sushil R K 1993. Application of physical system theory and goal programming to modeling and analysis of waste management in national planning *International Journal Systems Science* 24(5) 957–984.

Sushil R K. 1994a Flexible systems methodology *Systems Practice* 7(6) 633–651

Sushil R K. 1994b Flexible systems management: An evolving paradigm Communicated to the California Management Review.

Vrat P 1979 Waste management in India. the need for organized systems approach, Country Paper. APO Symposium on Waste Management, Japan

Wilson D. 1993 The landfill stepladder–landfill policy and practice in an historical perspective pp 24–28. *Wastes Management*

POWER GENERATION FROM MUNICIPAL SOLID WASTES THROUGH THE BIOMETHANATION ROUTE

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Introduction

Solid wastes have been produced since the beginning of civilization. It is becoming apparent that one of the major impacts of technological progress is a significant increase in the generation of solid wastes. The collection and disposal of solid wastes is a big task, taking into consideration the conventional disposal method practised, i.e., dumping. Land is an essential resource for waste disposal. A greater proportion of wastes is currently disposed of onto land in its crude state. Earlier, solid wastes were conveniently and unobtrusively disposed of as the density of population was low with large open land spaces. With the advent of industrialization and urbanization, the problems of waste disposal increased. High population density, intensive land-use for residential, commercial, and industrial activities have led to adverse impacts on the environment. With population always on the increase, the land available is dwindling as against the amount of solid waste generation which is increasing day by day. Also, civic services are coming under increasing strain. Existing disposal sites are getting exhausted and the legal and the financial problems of opening new disposal sites are causing delays which severely limit the availability of disposal sites

The term 'waste' implies that it is of no concern to anyone and is of no value The intrinsic value of the material as a resource or as an object of further utility has not been fully recognized

Adequate management techniques adopted in developed countries are available which can be applied to developing countries with suitable modifications. Such an effort has been

made to enunciate technological aspects taking into account the difference in waste characteristics, degree of industrial and economic development, financial constraints, and socio-cultural aspects.

Non-conventional energy production techniques like anaerobic digestion are seen as the most viable processes for the generation of energy while simultaneously taking care of solid wastes, as in the case of highly organic liquid effluents.

With 25 cities in India having a population of more than one million, there is tremendous scope for the treatment of municipal solid wastes (MSW). The municipal refuse of a city is proportional to the population and the figures vary from 0.4–0.5 kg per person per day The composition of refuse varies with the type of city, industrial development, and general living standards of the city. It also varies with the area of activity of the city from season to season.

Western Paques India Limited have realized the problem of disposal of MSW and have seriously considered the opportunity of generating power through MSW.

More than 800 MSW samples were collected from various cities over a period of 12 months and analysed at the R & D centre of Western Paques to establish the characteristics of solid wastes Thereafter, it was shown that MSW could be treated by anaerobic digestion, and, in the process, large quantities of energy in the form of methane-rich gas produced This gas has very good fuel value and can be used to produce electricity through gas engines.

Western Paques have successfully generated electric power from methane-rich gas generated through industrial wastes. With the development of this new technology of generation of gas from solid wastes of cities, the conversion from MSW to power is the logical outcome

Process description

MSW treatment plant

The treatment process is based on the anaerobic digestion of solid organic and biodegradable matter. The flow sheet showing the process is given in Figure 1. The treatment can be broadly divided into four sections:

- pre-treatment and segregation;
- anaerobic digestion Figure 2;
- recovery of organic manure; and
- effluent treatment and disposal.

Pretreatment and segregation

Receipt of MSW

The MSW collected from the various parts of the city shall be received in the storage area. It is further conveyed on refuse conveyers.

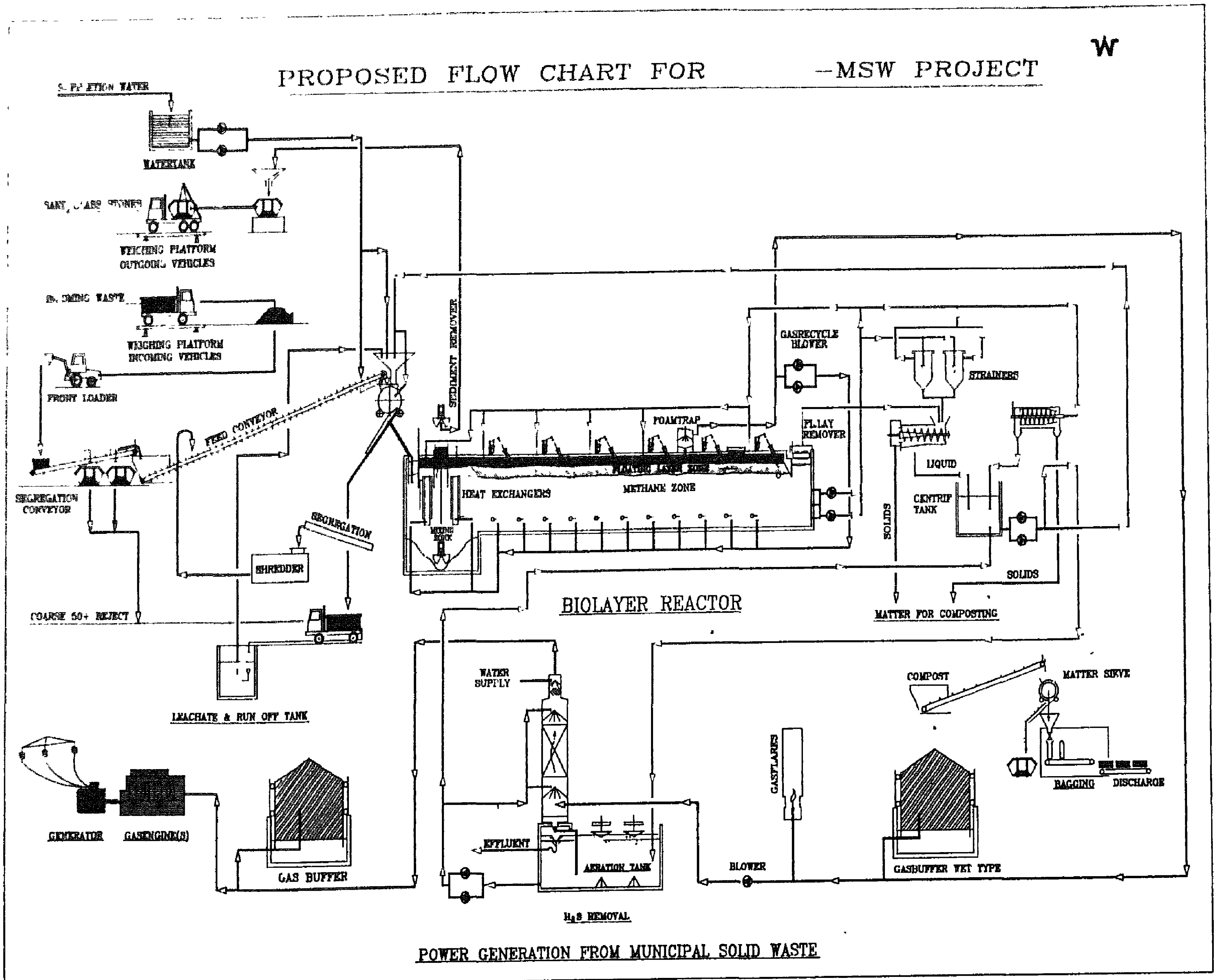


Figure 1. Power generation from MSW

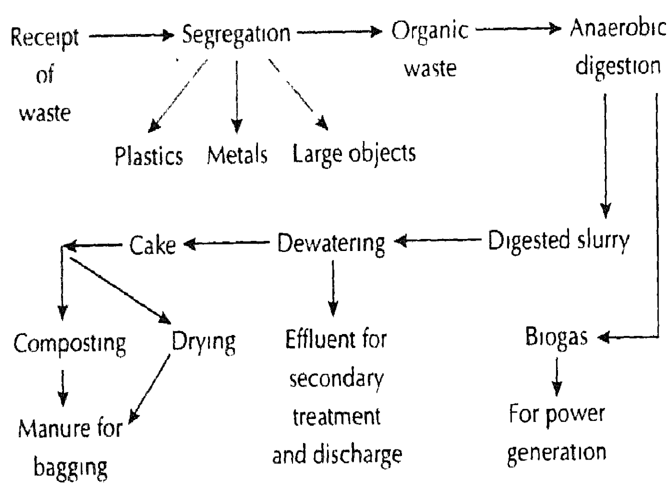


Figure 2. Anaerobic digestion of MSW

Segregation

After the segregation of very large pieces of wood, stones, plastics, rags, etc., the refuse is then taken into the rotating drum sieve. The sieve is rotated by electric motor and with a suitable reduction gearbox. The inner rotating sieve is comprised of perforated drums having an overall opening size of 50 mm.

The outer drum is a non-perforated drum. In case any lumps are present, they are broken down due to the rotating action of the drum. The water is spread on the refuse in the inner drum. By spraying water on the inner drum, the fine organic matter attached to large pieces are washed out in the outer drum. When the refuse passes into the inner drum, particles larger than 50 mm are separated and are conveyed by another conveyer system for further segregation. The material smaller than 50 mm size along with spray water is conveyed into the anaerobic digester.

The material that is larger than 50 mm size is subject to segregation to separate out the organic material from it. This portion is further shredded to less than 50 mm of size and recycled to the rotary drum sieve. The balance material is separated into plastics and others.

Anaerobic digestion

The remainder of the pretreatment is on the organic matter along with some fine earth or sand. This fraction will be made into a pumpable slurry with the help of the reactor effluent and pumped into the anaerobic reactor.

The anaerobic digester design is based on the floating layer technology. The floating layer anaerobic digester is basically a single compartment reactor The first part of the digester acts as a settling tank which has a suitable hopper bottom where the heavier portion is settled into the hopper. In this section, mixing is achieved by recycling of biogas through draft tubes. This agitation, due to the biogas, is effected through the washing of separated particles, and the organic matter is conveyed further to the anaerobic digester compartment. The anaerobic digester zone has a floating layer of the debris. Below the floating layer, the reactor design is based on the completely stirred vessel principle using com-

pressed biogas as the mixing device. In this zone, organic material from MSW interacts with biomass and undergoes anaerobic decomposition where biogas is produced and organic matter is stabilized. In the floating layer, organic matter which is much lighter than water accumulates. This organic matter further undergoes anaerobic decomposition and fatty acids are produced. These fatty acids are washed out into the mixing zone with the help of a spray of treated wastewater from the reactor.

Recovery of organic manure

To facilitate the handling and its ultimate disposal, the effluent from the reactor shall be subjected to dewatering by a screw press (for floating layer) and a centrifuge (for mixed liquor content of the reactor).

The floating layer is removed with the help of dunkers and open-end screws and further screw-pressed for dewatering the same. The dewatering liquor flows back into the reactor and the dewatered floating layer solids are removed from the screw press. These solids have about 40 to 60% moisture and have good soil-conditioning properties. The decanter is used to take out the mixed liquor content from the mixing zone of the anaerobic digester. The solid cake is discharged from the centrifuge containing stabilized organic matter along with the biomass. These solids also have excellent manure values and can be used for the same purpose. The moisture content in the cake discharged from the centrifuge is also about 20 to 30%, the consistency at which it can be easily shovelled. The organic fertilizer will be dried to 25% moisture content and packed in 5, 10, and 50 kg bags for sale.

The settled mass in the settling compartment of the digester is removed and is taken out on the conveyer belt. These solids contain mainly sand particles below 50 mm size. These solids are stored for drying and can be disposed of later along with the rejects of the drum sieve

Effluent treatment and disposal

The effluent generated in the process is subjected to aeration through the activated sludge process which renders it suitable for disposable as per statutory requirements.

Power generation plant

The power generation plant mainly consists of a gas cleaning unit, power generation equipment, an electrical system and other connected mechanical systems as shown in the block diagram in Figure 3.

- The mechanical system consists of a biogas engine with auxiliaries like the lube oil ignition, cooling, ventilation, and exhaust gas systems
- The electrical system consists of an alternator, a switchgear panel, transformers, and the outdoor switchyard to transmit power to the grid and the MCC panel for power supply to plant auxiliaries.

Gas cleaning unit

Anaerobic digestion of MSW produces biogas. This biogas contains hydrogen sulphide (H_2S) usually in concentrations of 0 1 to 0 2%. This biogas must be cleaned to reduce the

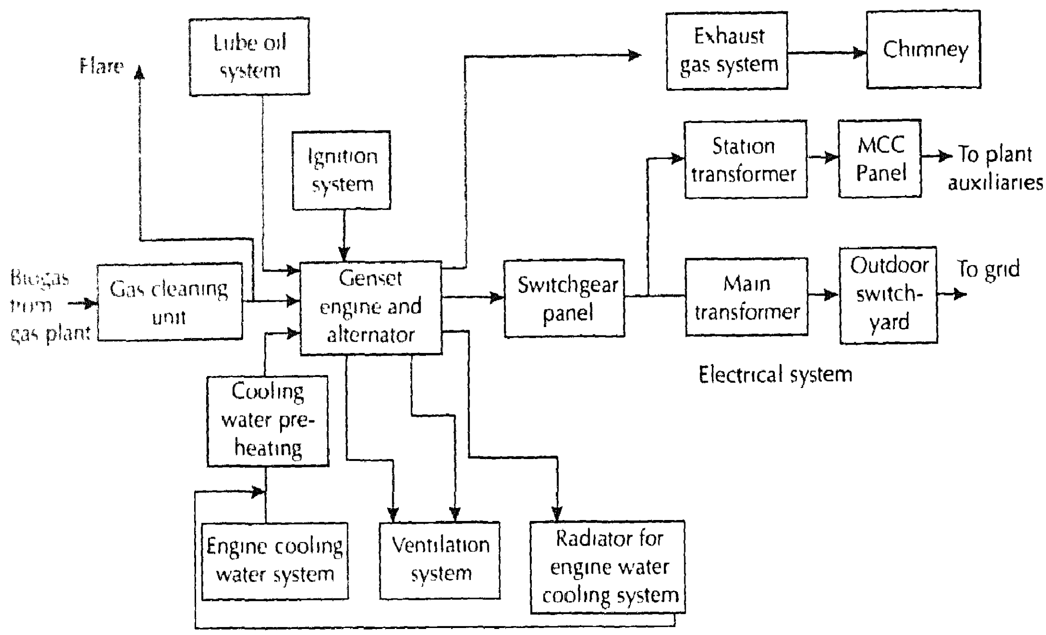


Figure 3. The block diagram of a power generation plant

H_2S concentration to a level acceptable to the biogas engine. This is done by spraying a stream from secondary treatment over a packed bed with a high contact surface. Biogas is made to enter from the bottom of the bed, concurrent to the above liquid, and is stripped of excess H_2S. Cleaned biogas is then taken to the biogas engine.

Biogas engine

The biogas engine is of the Jenbacher Energie System (Austria) make, spark-ignited, four-stroke, 16-cylinder, turbo-charged, after-cooled internal combustion engine. The biogas from the gas cleaning unit enters the engine where it is ignited with the help of an efficient and reliable spark ignition system. Internal combustion of the air–gas mixture in the engine cylinder leads to the generation of mechanical shaft power and heat. Mechanical shaft power is transmitted to the alternator, which is connected to the engine by a bell housing. The heat in exhaust gas (produced during internal combustion) can be utilized for the generation of hot water/steam.

The engine is equipped with a highly advanced microprocessor-based energy management system EMS-2000. Some of the salient features of this system include:

- speed control for no load and island operation mode;
- signal processing for electronic misfiring detection;
- output control for paralleling with grid;
- load balancing if several modules are operating independently,
- reverse power control;
- automatic lube oil replenishing system;

Socio-economic benefits

1. Leads to national savings on resource generation.
2. Takes care of the environment and energy, both on the national priority list.
3. Offers totally new opportunities of employment in a fast-growing sector.
4. Provides a hygienic atmosphere to the citizens and improves the quality of their life.
5. Paves the way for the image-building of the corporation to generate trust in their services and foster cooperation from people.

Conclusion

With increases in urban population and rapid industrial development, the pressures on environment are two-fold from the MSW. At Western Paques, these problems have been tackled very effectively and technologies suitable to Indian conditions have been developed. These not only treat pollution but also generate power with the help of methane generated in the process, thus saving the national energy sources. This will open up a new era of power generation from waste.

BIOENERGY FROM MUNICIPAL SOLID WASTES WITH TOTAL SOLID MANAGEMENT

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Introduction

Accumulation of garbage around human habitats is posing problems everywhere, varying only in degree. Accumulation of municipal solid wastes (MSW) in the city of Calcutta ranges between 3500 and 3800 tonnes/day; for its neighbouring city at Howrah, the same is around 750 tonnes/day and in Agartala in the state of Tripura it is around 150 tonnes/day Variations are mainly due to population, geographical location, environmental impacts, and habits of the people in the locality. To solve the problems in management of garbage, BSCL adopted the anaerobic treatment of MSW first at laboratory scale of 1 m^3 with total solids (TS) of five per cent and natural digestion where about 1.7 m^3/batch of biogas was produced with a feed of 7 kg/batch of organic fraction of MSW (OFMSW) every five days of hydraulic retention time (HRT). Solid retention time (SRT) was 30 days.

Encouraged by the laboratory-scale design, BSCL moved to a pilot-scale plant with a 15 m^3 biodigester at Tapsia in Calcutta with 1000 kg of MSW/batch, feeding 700 kg of OFMSW/batch into the digester maintaining TS of about 10%. The biogas production of the Tapsia plant is approximately 35 m^3/day, running a generator of 5 kW capacity for 6 to 7 hours/day. Following the observations on the performance at Tapsia, BSCL set up a similar plant at Howrah with World Bank funding through the Calcutta Metropolitan Development Authority (CMDA) with 15% TS and a feed rate of 700 kg/batch of OFMSW with a manual stirrer, temperature controller, and feed rate control However, any higher concentration of more than 18 to 20% was found to choke the traditional cylindrical digester. BSCL, therefore, went back to the laboratory and evolved a technique to handle biomass movement horizontally, by mechanical means, in a cylindrical digester,

similar to the plug flow type, and achieved the transportation of biomass with TS concentrations up to 30–35%. This approach leads to the use of a biodigester of 200 m^3 volume to handle 20 tonnes/day of OFMSW for producing 300 kW/day of electricity for Agartala, Tripura Design drawings have been finalized accordingly.

In contrast, should BSCL maintain five per cent TS like in the traditional Khadi Village Industries Commission (KVIC) model, 1200 m^3 would have been the volume of the digester with a massive mild steel (MS) structure and costs prohibitive to commercial (generation) use. Indigenous bioenergy, namely, electricity from MSW is right now limited to 50 kW capacity with parallel operations up to 100 kW capacity, as Bharat Heavy Electricals Ltd (BHEL) makes a 50 kW generator with a full biogas operation mode. M/s Kirloskar makes generators which require diesel to the extent of 15–20% – the only handicap today. BHEL expects to raise the capacity to 100 kW units shortly. Imported options for biogas generators could be considered and will be workable excepting the escalating costs of the project which need be considered on a case-to-case basis. Other than electricity, the plant under consideration has one major tangible output, namely, organic fertilizers of high nitrogen, phosphorous, and potassium (NPK) value (3:3:15) at 3000 kg/day from a 20 tonnes/day OFMSW plant, which could fetch a good price of Rs 25/kg from tea gardens during plantation for horticulture and sericulture, namely, saving of expenses on land – another aspect to be considered in evaluating the techno-economics of the project. Recycling of MSW to the extent of 30–40% will be another added value, primarily for land filling. The fifth and final output which should be weighted in evaluating the merits of the project is the pollution-free environment thus created, in the absence of which there could have been serious health hazards.

Indian scenario

In India, the Ministry of Non-conventional Energy Sources (MNES) has already launched an ambitious national programme of turning wastes into wealth. BSCL, with its modest beginning, desires to take a segment of shares in power generation and organic manure production from MSW. In order to generate full-fledged grid-acceptable power indigenously, India is yet to step up their manufacturing programme on biogas generator sets operating on 100% biogas (60% methane rich) to the capacity of 1 MW level. As such to make bio-energy (electricity) competitive when compared to the traditional power generation mode, India needs to emphasize indigenization of biogas gensets beyond 1 MW.

BSCL's achievements

BSCL has made strenuous R & D efforts over a decade through lab-to field-to-lab techniques, and have mastered garbage management to such a level that they can take up challenges on MSW management of different capacities ranging from 20 tonnes/day of MSW to 200 tonnes/day of MSW with multiples of generators of 50/100kW, matching indig-

enous availability towards production of electricity at 300 kW/20 tonnes/minimum plant size, and multiples thereof, fitting under the spectrum of urban/district level municipalities.

Annexure I reveals the characteristics and performances of BSCL's activities in two pilot plants at Tapsia and Howrah in the state of West Bengal for 5 kW power for 6–7 hours, absorbing 700 kg of OFMSW. These two plants have been used to generate data for the development of scaled-up plants to 20 tonnes/day to meet demands for various districts in West Bengal in the vicinity of Calcutta for the production of biogas for firing bricks, and replacing C Grade coal. Another two such plants are being worked out for the production of electricity and biogas bags for emergency supply to hospitals and for domestic consumption in urban areas respectively. BSCL is also forging ahead in resolving the problems in garbage management with a cost-effective approach with high TS management. Figures 1a and 1b show the mass balance and energy balance for BSCL's plants at Tapsia and Howrah which use traditional cylindrical biodigesters of the KVIC model with improvements/additions in mechanical scum breaking, periodic manual agitation, control of temperature,

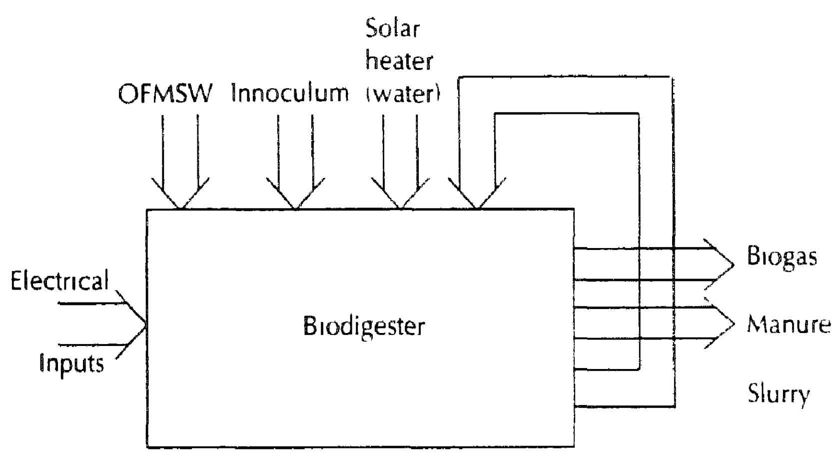


Figure 1a. The energy balance diagram (see Annexure I)

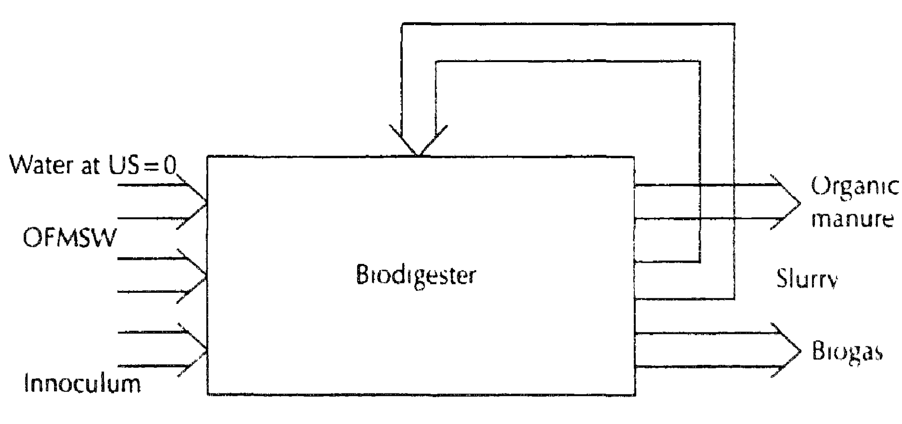


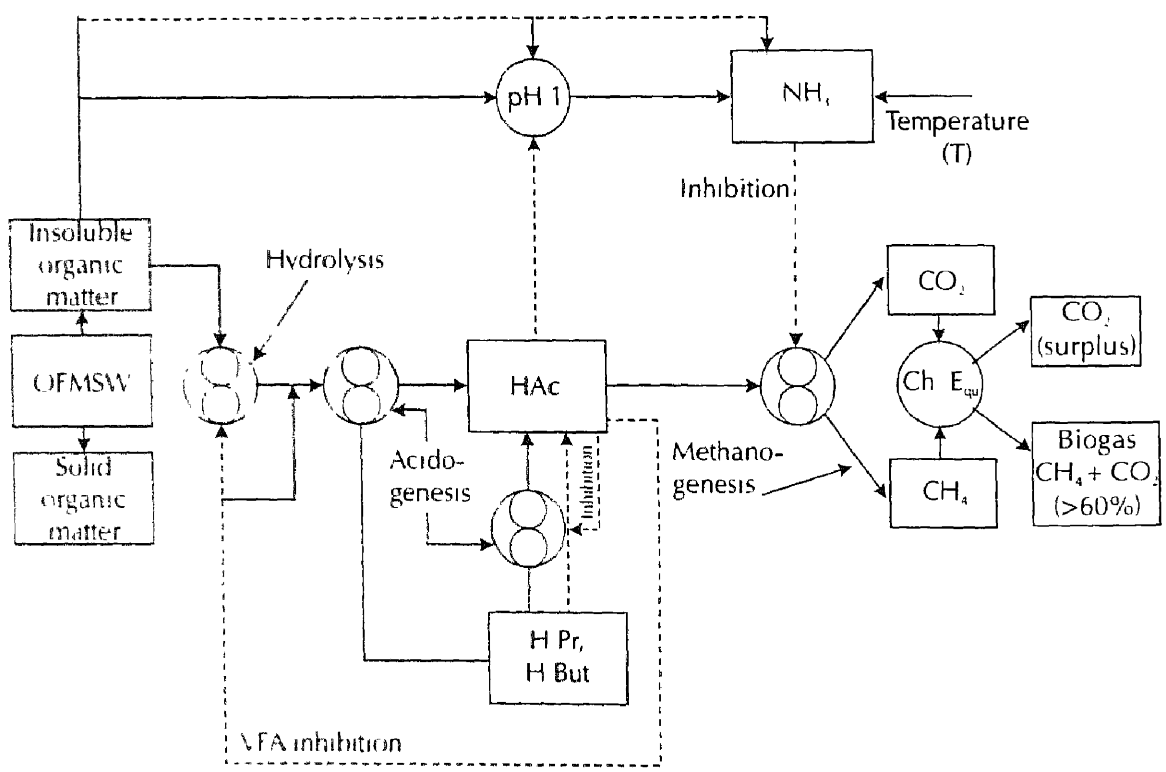
Figure 1b. The mass balance diagram

and pretreatments of MSW. However, in spite of all these changes, BSCL has found the KVIC model could not be used for further scaling up MSW disposal because of the following reasons:

- shock loading cannot be avoided;
- temperature controlling posed a problem;
- HRT was difficult to bring down;
- as a result, virtual SRT of one day could not be organized; and
- higher TS operations choked the plant.

Technology for high TS

Before technology and/or engineering is evolved, basic science aspects need to be stressed briefly. MSW, having been presorted to OFMSW while passing over a conveyor belt that is driven manually to save energy, is passed through pretreatment stages, namely, crushing, shredding down to pieces, mixing, and predigestion (semi-anaerobic). Following the pre-digestion stage, OFMSW is allowed to be fed to the anaerobic digester at a predetermined rate dictated by mathematical modelling of biogas production. Figure 2 explains the biogas model in a two-phase process – acedogenic and methanogenic – leaving the slurry



biological conversion; chemical equilibrium; ⟶ material flow; ---→ modulation; ▭ matter,
pH 1 NH important tool for MSW controlling biodegradation of solid volatile fatty acid (VFA)

Figure 2. Biogas modelling using MSW as biomass

to be processed for composting as organic manure. Methanogenic bacteria are being cultured in the field laboratory attached to the pilot plant, and are mixed during feeding OFMSW, enhancing the rate of reaction in the biodigester. The prime parameters controlled in the digester where the feed rate in synchronism to the exponential bacterial growth rate for continuous operations avoiding shock loading of nutrients (OFMSW) into the digester This approach also helps in attaining near 24 hours HRT. Virtually 24 hours of SRT has been attained through the longer passage of biomass in the scaled-down 1 m^3 model with a special screw-simulated mechanical vane type biomass conveyor inside the horizontal and tubular biodigester. The passage rate of the biomass has been controlled such that virtual one day of SRT is faced by each entry of OFMSW/day.

Figure 3 shows variations of biogas production with temperature, TS, pH, etc., of the digester under controlled operations. The temperature of the biodigester is controlled through the jacketed construction block around the tubular structures through the circulation of hot water from a feed tank. Provisions for heating water include electric heating for the start-up period and the emergency period other than the solar and engine heat recovery system. With controlled feed rate both at the laboratory and at the pilot plant, it was observed that the digester did not get choked. For the disposal of 25 to 30 tonnes/day of MSW or 20 tonnes/day of OFMSW, a digester of 200 m^3 of the 33 m length and 4 m diameter has been designed in 15 segments with an appropriate sealing and control gear to be operated manually from outside. The 200 m^3 digester will have a steel structure weighing about 30 tonnes. Other plant equipment include the biogas holder and a specially developed biogas compressor to compress the biogas at 1.3 to 1.6 bars for feeding into the biogas genset Appropriate gauged scrubbers are also included to remove CO_2 and enhance the CH_4 percentage approaching 80%. Plant characteristics and economics have been evaluated in Annexure II for 20 tonnes/day of OFMSW or 25–30 tonnes/day of MSW plant size utilizing high TS management. According to the observations, availability of high OFMSW and high TS could be enhanced provided appropriate steps are taken at the municipality level towards speedy/timely collection. The collection drive needs to be organized twice per day depending on the generation/accumulation of MSW in the region under consideration, avoiding natural biodegradation/loss of organic fraction of MSW.

BSCL's model emphasizes avoiding exhaustive use of power for plant equipment/processes. As such, more of natural/human power have been kept in mind for efficient operations of the plant, namely, use of solar power for process hot water requirements, solar photovoltaic power for cathodic protection of plant equipment, use of gravity hopper feeding into crushing and shredding operations, and use of manual sorting of inorganics from MSW, while passing over a conveyor belt that is driven manually.

Techno-economics

A techno-economics study on 25 tonnes/day of MSW has been done and found to be fairly acceptable with a simple payback of about two years. Benefits of such plants as outlined are manifold and all the benefits have been weighted in making the cost/benefit analysis. For example, intangible benefiting on the environment have been taken as lump sum money

unlike traditional practices of project evaluation where only tangible/visible benefits are taken into account for commercial evaluation. Annexure III gives such an analysis for a 25 tonnes/day of MSW.

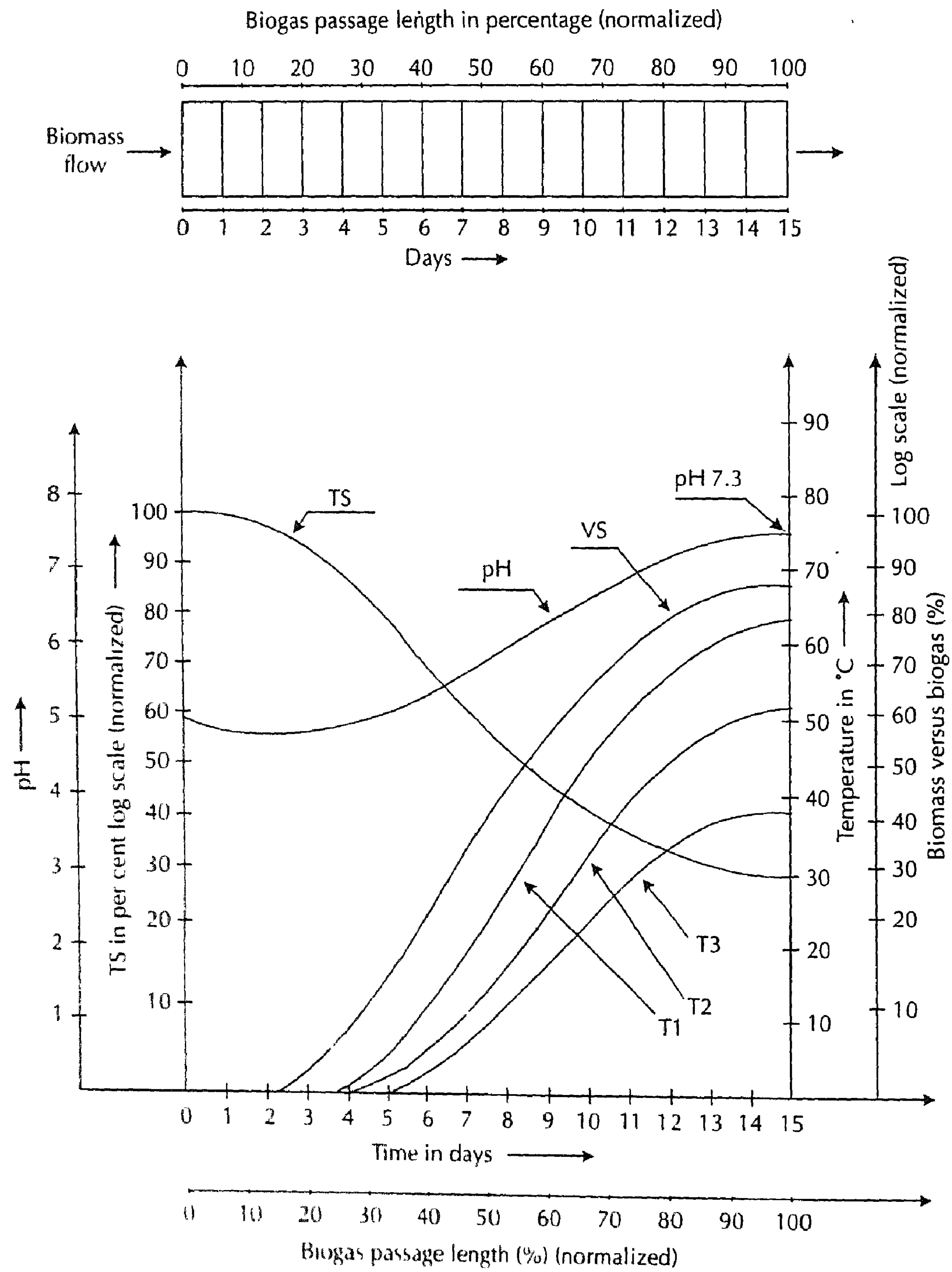


Figure 3. Biogas production rate as function of temperature, pH, TS/VS, time in days and biomass, and biogas length

Conclusion

It is, therefore, seen that the anaerobic treatment of MSW, in particular, and waste, in general, proves to have multiple benefits apart from meeting power requirements in rural/ remote areas in an emergency or otherwise. Other benefits include the enrichment of the organic content of the soil in the adjoining areas of operation for horticulture, tea production, sericulture, etc. Future prospects of high quality fuel oil as a substitute to gasoline cannot be ruled out once the acidogenic phase could be tapped/engineered appropriately. Disposal of waste leading to a pollution-free environment is the prime emphasis of the project with tangible benefits coming out in the process. BSCL is looking forward to join hands with the National Programme on Waste Management to benefit the nation at large.

Annexure 1

Characteristics of the bioenergy pilot plants at Tapsia and Howrah

Bio-energy plant

Plant parameters

- Plant input: 700 kg of OFMSW/batch
- Batch run: 5 days
- TS in digester: 15/10% for Howrah/Tapsia
- TS in OFMSW: 50%
- Organic manure @ 15% of OFMSW: 105 kg/batch
- Organic manure TS (dry weight): 52.5 kg/batch
- Slurry for feedback with 52.5 kg (TS dry weight) plus 350 kg water at 15% TS in the digester: 402.5 kg/batch

Plant inputs (energy equivalents)

- Electricity for plant equipment operation @ 25 kW/batch @ 857 kcal/kWh: 21 425 kcal/batch
- OFMSW @ 700 kg/batch with TS (50%) = 350 kg/batch; volatile solids (VS) = 0.7 of TS = 245 kg/batch; biogas = 0.75 of VS = 34.5m^3/batch; say 35 m^3/batch; heat equivalent energy = 5500 kcal/m^3 × 35 m^3/batch: 946 000 kcal/batch
- Innoculum as cowdung lab cultured @ 1% of OFMSW = 7 kg/batch TS @ 30% = 2.1 kg; VS equivalent @ 70% of TS = 1/3.47 kg/batch; biogas equivalent @ 0.7 m^3/kg of VS = 1.029 m^3/batch; heat energy equivalent @ 5500 kcal/m^3: 56 595 kcal/batch
- Slurry fed back @ 15% of OFMSW with 15% TS, namely, 52.5 kg/batch with equivalent heat energy @ 3575 kg VS and 25 725 m^3 biogas: 141 487 kcal/batch
- Solar heat energy @ 700 kg water/batch to raise, say, 10 °C: 7000 kcal/batch
- Total plant input: 1 151 082 kcal/batch

Plant outputs (energy equivalents)

- Biogas @ 172 m^3/batch (70% methane; 30% CO_2); heat energy @ 5500 kcal/m^3: 946 000 kcal/batch
- Organic manure 52.5 kg/batch (dry weight), namely, TS @ 15% of OFMSW/batch; VS equivalent @ 70% of TS = 3675 kg; biogas gas equivalent @ 0.7 m^3/kg of VS = 25.725 m^3/ batch heat energy equivalent @ 5500 kcal/m^3: 141 487 kcal/batch
- Balance 15% of TS, namely, 52.5 kg (dry weight) with water of 350 kg equivalent slurry is fed back to the input for regeneration in the bio digester/batch: Nil
- Total plant output (heat energy equivalent): 1 087 487 kcal/batch
- Plant efficiency. 94.475%

$$= \frac{\text{Plant energy outputs}}{\text{Plant energy inputs}} = \frac{1\,087\,487 \text{ kcal/batch}}{1\,151\,082 \text{ kcal/batch (\%)}} = \text{say } 94.5\%$$

ANNEXURE II
Bioenergy plant characteristics (techno-economics)

(For disposal of 30 tonnes/day MSW for 400 kW power for 20 hours/day
and 3000 kg/day NPK manure)

Objectives

- To exploit maximum feasible bio-energy for continuous operations
- To make a bio-energy plant economically attractive
- Plant sizes· 25/30 tonnes/day of MSW as biomass

Plant parameters

- Plant input (disposal of MSW): 25/30 tonnes/day
- OFMSW available @ 80/70% conversion level depending on locality: 20/21 tonnes/day, say, 20 tonnes/day for easy evaluation
- Available TS if collection drive is appropriately organized (which is a must) @ 50% on an average: 10 tonnes/day = 10 000 kg/day + 0 040 kg (innoculum + 370 kg (slurry fed back) from mass balance analysis) = 10 410 kg/day.
- Available VS in an optimally controlled plant as per laboratory evaluation results: 8000 kg/day + 100 kg (innoculum) + 1859 kg (from slurry fed back) = 9959 kg/day
- Biogas available from the plant under above conditions @ 80% of VS available and @ 1 m^3/kg of VS: 8000 m^3/day
- SRT at start-up till steady state is reached as per laboratory evaluation: 10/15 days
- Virtual HRT attainable with the biomass passage controlled along the digester: 1 day
- Volume of the anaerobic digester of MS structure: approximately 200 m^3 in 15 segments
- Weight of the digester with a steel structure: 30 tonnes in 15 segments
  Maximum power generation possible @ 400 m^3/hour in multiples of 100 kW: 400 kW for 20 hours = 8000 kWh/day
- Organic manure available with 45% moisture content and 20% of TS (total) input: 3000 kg/day
- Feeding rate of biomass (OFMSW) from the mixing tank into the biodigester round the clock: 833 kg/hour (for 20 tonnes/day)
- Feeding rate of water including (9624 + 3706) kg/day: 555 kg/hour (for 3.33 tonnes/day)
- Biomass passage along the digester (20 tonnes to travel in 15 days). 1 33 tonnes/day
- Rate of flow of biomass along the digester (to travel the 30 m long digester in 15 days): 2 m/day and 8.3 cm/hour
- pH to be maintained: 6.8 to 7.3
- Temperature to be maintained with a feedback of hot water circulation in the digester jacket · 37 + 2 °C
- Methane content in biogas: 60–70%
- Captive energy consumption/day limited to percentage of energy generated: 20%
- TS exit: 20%
- N:P·K value of organic manure: 3:3:1.5

Plant efficiency

- Mass balance. 96.06%
- Energy balance: 94.6%

(Techno-economics as per Annexure 3· positive)

ANNEXURE III

Plant economics: bio-energy from biomass (MSW)

1. Plant input (disposal of MSW): 25/30 tonnes/day (being area-specific)

2. Plant outputs (tangible)

- Biogas: 8000 m^3/day
- Electricity: 8000 kWh/day
- Organic manure NPK (3:3:1.5): 3000 kg/day
- Recyclable MSW: 10 tonnes/day

3. Plant cost (outlay) (Rs in million)

- Biogas genset system: 7
- Biodigester MS 200 m^3: 4
- Plant and equipment: 10
- Manure processing facilities: 2
- Plant erection and commissioning: 1
- Total plant outlay: 24

4. Plant operating cost (in millions): 3.6 (@ 15% of plant outlay without considering cost finance)

5. Plant benefits (tangible and intangible) (Rs in million)
- Electricity only @ Rs. 2.25/kWh: 5.4
- Biogas only 4000 bags/day of 1 m^3 at 2 bars @ Rs. 5.00/bag: 6
- Organic manure : 2.25
- Recyclable MSW @ Rs 100/trucks (@ 5 tonnes/truck): 0.06
- Land savings @ 2 acres/year @ Rs 1.5 million/year (for Agartala): 3
- Cost of a pollution-free environment: 3
- Total plant benefits (w/o 5.2) : 13.66

6. Cost/benefit analysis

- Plant cost (outlay): Rs 24 million
- Plant benefits: Rs 13.66 million/year
- Cost/benefit ratio (simple payback)

$$= \frac{\text{Plant outlay}}{\text{Plant benefits/year}} = 21 \text{ months}$$

7. Operating cost: Rs 3.6 million/year

8. Justifications

- Plant benefits will improve considerably once total heat loss from a biogas engine running at 16% efficiency is utilized for heating water appropriately for use in hospitals, hotels etc.
- Plant benefits will marginally improve from sale of biogas bags only for domestic usages, namely cooking @ 5/6 hours per filling @ 2 m^3 biogas/1 m^3 bag to 18 months (capital outlay at 22 million tonnes and benefits @ Rs. 14.26 millions/year).
- Plant benefits derived are of national importance for creation of a pollution-free and eco-friendly environment out of the anaerobic disposal of MSW, which, otherwise, could have created an epidemic at times. As such, operating such plants even with subsidies would pay in the long term, benefitting human habitat both nationally and globally.
- Power generation for 20 hours/day has been kept in mind from the point of view of the practicality of maintenance and better operational efficiencies.

BIOMETHANATION OF PREHYDROLYSATE LIQUOR USING FULL-SCALE UASB REACTORS

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Introduction

In India, enormous quantities of effluents are generated from various industries which need to be treated before their disposal into the natural habitat. Otherwise, the pollution load to the aquatic environment would pose a great threat due to the contamination of river water and groundwater. Particularly, organic effluents generating from various agro-based industries such as distilleries, pulp and paper, and rayon grade pulp are responsible for greater damage. These industries, therefore, must look for an appropriate technology to treat their effluents profitably Considering the need for treatment of such effluents, WPIL have acquired a high rate biomethanation technology patented as 'BIOPAQ' from M/s PAQUES B V of The Netherlands, which is based on the principal of the upflow anaerobic sludge blanket (UASB) process. The main advantage of these high-rate biomethanation technologies is that by treating the effluent to a greater degree, they simultaneously produce methane-rich biogas which can be used for meeting the partial heat requirements of a particular industry or for the generation of electricity when used in engines coupled with alternator.

Development of specific know-how

The application of any high-rate biomethanation technology strongly depends on the characteristics of the effluent and the environmental conditions. This is specifically true for

UASB because of its inherent technological requirements. Keeping this in mind, WPIL acquired basic engineering know-how from PAQUES B V. The development of specific know-how for each effluent is being done at its R & D centre, through bench- and pilot-scale studies. Upon the successful completion of pilot-scale studies, commercial-scale plants are being erected for operation in various kinds of industries. However, the treatment of prehydrolysated liquor (PHL) emanating from the Harihar Polyfibres (HPF) is a specific case of interest as it is the first of its kind in the world. WPIL have conducted pilot-scale studies at the site, and, based on its successful performance, a full-scale commercial plant has been erected and is being operated by WPIL under the build, own, operate and transfer (BOOT) scheme.

Generation and characteristics of prehydrolysate liquor

At HPF, rayon grade pulp is manufactured using eucalyptus wood as raw material. The process involved is the digestion of eucalyptus wood chips in water known as prehydrolysis at high temperatures. In this process, the alpha-cellulose is separated. The digestion process is a batch process. At the end of each batch, the digester is drained and the pulp is taken into a second-stage chemical digester. The effluent drained out is called PHL, which is at temperature of 100 °C and has a high chemical oxygen demand (COD) in the range of 76 000 to 80 000 mg/litre and a pH of 3.2 to 3.8.

Process configuration and the BIOPAQ technology

The heart of the total process is the two BIOPAQ reactors operating in parallel. A schematic flow diagram is shown in Figure 1. Apart from the BIOPAQ reactor, the scheme comprises a buffer tank which is essential for pre-acidification, a flash mixer which is required for mixing PHL, recycle and alkali backwater (for dilution purposes), and holding tank which stores raw PHL. The biogas generated is being supplied to HPF through gas holder and a gas booster.

The BIOPAQ system is an anaerobic reactor based on the UASB principle. A schematic sketch of BIOPAQ is shown in Figure 2. It consists of a corrosion-resistant reactor which incorporates a unique three-phase settler to separate the sludge, biogas, and the effluent. The settler is located at the top of the reactor and is designed for specific COD loadings and hydraulic throughput.

An internal distribution network is located at the base of the reactor. This network is designed to distribute the flow evenly throughout the bottom of the reactor. This eliminates short-circuiting and promotes proper formation of well-settling sludge, which is a critical factor in the reactor operation. This distribution network is designed to facilitate easy cleaning, thereby eliminating potential plug-in problems. The biogas produced by the bacteria is in the form of small bubbles which float upward through the sludge bed and

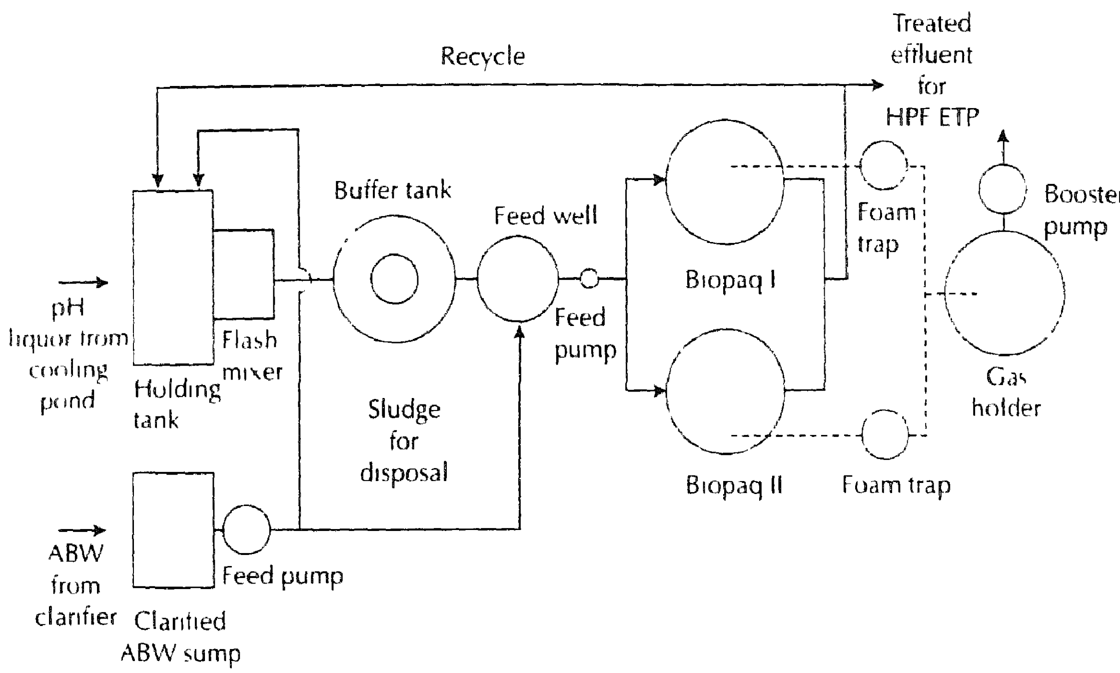


Figure 1. The flow scheme of the biogas plant for HPF

blanket zones and provide a natural mixing action When the biogas reaches the top of the reactor, it is removed by the gas collectors A gas-free zone above the collectors makes it possible for the settling of finely dispersed solids to the reactor bottom.
Other specific features of the BIOPAQ include:

- high treatment efficiency,
- high gas production,
- ability to withstand hydraulic and organic shock loadings;
- directly combustible gas;
- low space requirement;
- low sludge production;
- low energy requirement;
- low operating and maintenance cost;
- sludge storage for extended periods of time; and
- quick start-up.

Performance of the system

The commercial plant is being operated for the past one year and the results show encouraging trends The biogas produced is being supplied to hot air generators or lime kilns

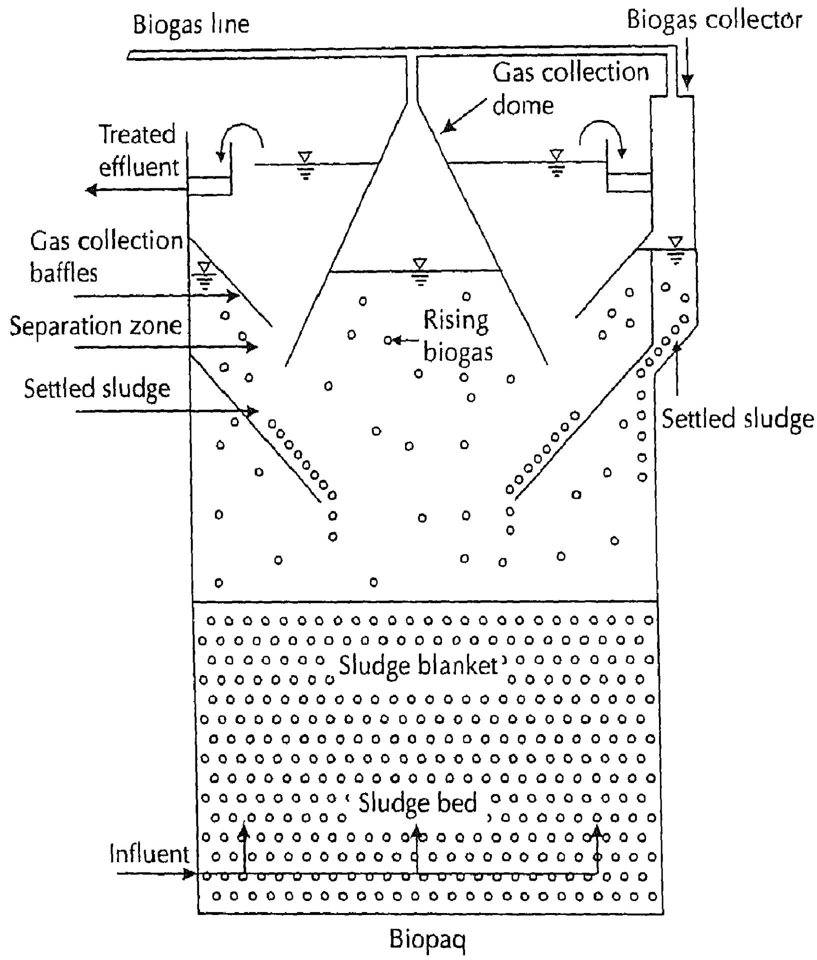


Figure 2. Schematic diagram of the UASB reactor

or boilers depending upon the plant requirement. The performance at full load is given below.

- Flow of PHL: 640 m^3/day
- Average COD concentration: 76 000 mg/litre
- pH: 3.2 to 3.8
- Flow of alkali backwater: 840 m^3/day
- COD reduction: 65 to 70%
- Gas production: 16 000 m^3/day
- Specific gas production: 0.5 to 0.55 m^3/kg COD reduced
- Methane content: 65 to 70%

Section 7

Biomass-based power generation

BIOMASS ENERGY: THE UK PROGRAMME

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Introduction

Electricity from biomass has the potential to become one of the largest contributors of renewable, sustainable energy in the UK and many other parts of the European Union. It will not, however, achieve this potential unless the cost of electricity from biomass can be competitive with that from other sources. The use of high-efficiency power generation cycles based on gasification and pyrolysis processes, combined with dedicated energy forestry, is one of the most promising ways of achieving this potential. The realization of this has led to a number of recent policy initiatives in the UK, the most notable being the introduction of the non-fossil fuel obligation (NFFO) for this technology area and an active industrial support programme known as the New and Renewable Energy Programme (NREP).

This paper describes the UK view on biomass energy and some of the policy and support measures that have been put in place to develop the technology

UK government policy

The government policy is to stimulate the development of new and renewable energy technologies where they have prospects of being economically attractive and environmentally acceptable in order to contribute to diverse, secure, and sustainable energy supplies; reduction in the emission of pollutants, and encouragement of internationally competitive renewable energy industries.

The Coal Review White Paper recorded the government's intention to work towards a figure of 1500 MW of new renewable electricity-generating capacity in the UK by the year 2000. The making of NFFO orders under the Electricity Act of 1989 is the government's main instrument for pursuing the development of this capacity.

The purpose of these orders is to create an initial market so that in the not-too-distant future, the most promising renewables can compete without financial support. This requires that there is a steady convergence under successive orders between the price paid under NFFO and the market price. This will only be achieved if there is effective competition in the allocation of NFFO contracts.

The implication of UK policy is that biomass energy must be able to show a clear path by which it can become competitive with other fuels. To achieve this, we must attain two goals.

- a high efficiency conversion technology with a capital cost less then £1100/kWh, and
- biomass price less than £1.3/GJ.

NFFO

NFFO is the main policy instrument for achieving UK's target of 1500 MW_e of renewable electricity capacity by 2000. In brief, this is a premium price electricity scheme whereby the government obliges the electricity supply companies to buy a certain amount of electricity from generators using a range of renewable sources. The actual price paid depends upon the renewable technology and is set by a competitive bidding procedure.

NREP

In addition to the market creation measures of NFFO, the UK also has a market enablement programme – NREP, that concentrates on providing support for the UK industry In the biomass area, this support is concentrated on energy crop–fuel supply chains, conversion processes, and tools to evaluate and optimize complete biomass energy systems

Energy crops

The UK does not have a lot of conventional forestry. Less than four per cent of the land area is covered by forest – which is less than any other European country Thus, if we are to get any substantial amount of energy from biomass, it must come from dedicated crops. For the UK, the most suitable crop is arable coppice. This is a modern version of the very old practice of coppicing, or cutting some varieties of tree close to the ground to force branching The growth is then always at its most vigorous. Modern cultivation involves the planting of around 10 000 cuttings per hectare, cutting back after the first year's growth and then taking a harvest of fuel by cutting back every third year Willow and poplar are

mostly used, although other species may be suitable in some areas. Typically, the wood is harvested with modified machines that were originally developed for use with maize and sugarcane.

The UK programme is supporting industry in a number of ways to promote the commercial application of arable coppice. The guiding principle is to concentrate on those areas where there is a significant technical risk. Thus, work is being carried out on.

- the effects of soil and clone selection on crop performance,
- willow rust control;
- biodiversity and other environmental impacts,
- storage and drying,
- harvesting machine development; and
- transport logistics.

This work has succeeded in identifying and addressing many uncertainties in the arable coppice fuel chain and has put the UK industry in the position of being able to supply to a number of planned power generation projects submitted as part of the NFFO. Most of the work carried out by the programme in this area is published in reports which are available from the ETSU Enquiries Bureau

Advanced conversion technologies

As stated above, government policy is to support the development of technologies that have the potential to compete with fossil fuels within a reasonable length not only to grow the fuel at low cost but also to convert it to electricity in a highly efficient manner.

Conventional fossil power generation technology has always increased the conversion efficiencies by using a more complex steam cycle that requires large and larger plant sizes to be cost-effective. However, biomass cannot use this route as the size of the station is determined by the size of the fuel resource. In the UK, this will rarely exceed 30 MW_e.

The advanced conversion processes of pyrolysis and gasification offer greater efficiencies than combustion-based steam cycles at the sizes appropriate to biomass. These high efficiencies are achieved by first converting the solid biomass to liquid (pyrolysis) or gaseous (gasification) fuel, then burning these intermediates in engines or gas turbines. By doing this, the heat is converted to power at a higher temperature than in the simple steam cycle giving the potential for a thermodynamically more efficient process

There are a number of possible markets that could develop in the UK. It is feasible to build larger-scale plants, between 25 and 30 MW_e in the more arable parts of the country. However, medium-scale plants of 5–15 MW_e may be more suitable in mixed farming areas. There also seems to be demand for small-scale heat and power at a size of a hundred or less kilowatts. The new technology of flash pyrolysis is also attracting a great deal of attention from power plant developers in all these markets because of its inherent flexibility

The UK NREP is supporting industry in developing technologies for all these market sectors. As with arable coppice development, the principle is to help the industry overcome technical risks by supporting R & D activities.

Large-scale gasification plant

Fluidized-bed gasifiers operating at atmospheric pressure are probably the best option at this size. Electricity is more likely to be generated using a combined cycle gas turbine

It is likely that due to the economies of scale, these large plants will produce the most competitive power for grid connection. In recognition of this, the European Commission announced in 1993 that they would part fund the building of one or more demonstration projects using biomass gasification to produce power. Fluidized-bed reactors and gas turbine cycles were preferred and the fuel supply was to be short rotation coppice. One of these projects, 'Project ARBRE', is located in the UK and has been awarded a contract under the NFFO arrangements.

The main participant of Project ARBRE is Yorkshire Water who is working with TPS from Sweden and other European companies. The main parameters of the project are

- 2000 hectares of willow and poplar short rotation coppice;
- yields enhanced by sewage sludge application to the coppice;
- TPS gasification technology;
- EGT Typhoon gas turbine in a combined cycle with exhaust firing;
- 8 MW_e exported power,
- total project cost including the first year's operation is 36.4 million ecu;
- 31% electrical efficiency; and
- planting in spring 1996 and first fire in 1998.

As Project ARBRE is very much in line with the UK policy, the National Programme actively encouraged the project by funding pilot plant work and design studies The intention is to support the independent monitoring of both the power plant and its associated fuel supply.

Medium-scale gasification plant

The most suitable unit in this range is likely to be the fixed-bed updraft gasifier which supplies a fuel gas to a reciprocating engine. This is a simple unit that gives the low capital cost essential for economic projects at this size. Efficiency will be moderate at 30–35% when compared to the large gas turbine combined cycle (44%) This efficiency is still, however, substantially above that of the comparable steam turbine plant. A further advantage of this type of plant is the high temperature heat rejected from the engine that can produce substantial quantities of steam or hot water This feature makes it particularly attractive for cogeneration or for agro-processing industries.

The major area of technical uncertainty with this technology is the removal of the large quantities of tars from the gas produced from the engine inlets and valve, soon causing failure Work is being supported by NREP in removal processes, primarily catalytic cracking to lighter hydrocarbons This work has been successful so far and we are hoping to see the first demonstration built under the NFFO arrangements in the near future

The UK company, Wellman, has been supplying fixed-bed gasifiers for coal for many years and should soon be in a position to deliver a turnkey biomass power plant

Small-scale gasification

Currently, the fixed-bed downdraft gasifier, coupled to an internal combustion engine, is the only available option. This simple concept is derived from wartime applications in Germany and Sweden. The great advantage of these units is that the reactor destroys *in situ* the tars formed as the wood breaks down. Elimination of this tar is essential as it causes serious damage to the engine. While this design is simple, the unit must be supplied with a dry, regularly-sized wood feedstock if the tar elimination process is to be effective.

The simple design, combined with a mass-produced engine, gives a generating set with low capital cost. The conversion efficiency from biomass to electricity is around 20–25% with the added potential of extracting heat from the engine exhaust and jacket.

NREP has carried out a number of studies in this area and supported demonstrations with mixed success. As a result of these activities, we have come to the conclusion that for a small-scale wood gasification system to be economically viable, there are a number of criteria that must be fulfilled. These include:

- substantial internal demand for both heat and electricity;
- equipment cost below $800/kWe;
- low feedstock price;
- electrical efficiency over 20%;
- minimum operating labour, and
- availability for over 5500 hours per year.

Experience from the Enniskillen College combined heat and power (CHP) project has shown that the equipment cost target is attainable, but reaching high availabilities with a low manning level will be very difficult. This was underlined in a further study carried out under the JOULE II Programme where availability was singled out as being of paramount importance for the economic operation of any power plant in this size class. It has been said that the combination of low manning and high availability has proved very elusive with this technology, and some further development or new thinking is most certainly needed

INDEPENDENT RURAL POWER PRODUCERS: AN INSTRUMENT FOR SUSTAINABLE RURAL DEVELOPMENT

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Dasag Seuzach, Switzerland

Independent rural power producers

An independent rural power producer (IRPP) is a small decentralized power-cum-energy service company set up under the principles of a social-market economy to meet the power needs of small consumers in a small town or village. An IRPP will use energy resources that are renewable and locally available and operate on a commercially viable basis. While promoting sustainable development at the community level, it will also eliminate net CO_2 emissions and thus automatically help reduce the risks of global climate change.

In principle, IRPPs are for small towns and villages what independent power producers (IPPs) are for the centralized power and industrial sectors. However, in practice, they come with a strong socio-ecological orientation. Such an instrument is urgently needed in such areas of developing countries (DCs), where most of the poorer sections of society, including large numbers of marginalized women, still live. These people represent more than 30% of today's global population. These areas have been almost entirely bypassed by the industrial development process and what happens here during the next few decades will be of utmost significance for national and global sustainability. A look at the current situation of the power sector of DCs will immediately show how urgent it is to introduce integrated solutions in the rural power sector of these countries.

The current situation of the power sector in DCs

The conventional power sector policy in most of the DCs is based on the concept of centralized power stations using fossil fuels such as coal, oil, or gas, and hydro-electric

plants where adequate water flows are available. The types of centralized stations in DCs are listed below.

- *Fuel source based power stations* which include mine-mouth coal-fired stations, and oil-/gas-fired stations located near oil/gas fields, oil refineries, or ports. These usually generate power with large unit ratings and transmit it over long distances by high voltage (HV) transmission lines.
- *Load centre power stations* which are located near industrial/urban consumption centres. Coal-fired stations receive their fuel supplies from mines or ports by rail, road or water ways over long distances. Oil- and gas-fired stations receive their fuels by pipelines, sea tankers, or land transportation. These power stations supply regional and local loads through shorter HV transmission lines.
- *Large hydro-electric stations* which are generally located far away from load centres.
- *Captive power stations* built by the industry to meet its own load.

Such a power sector based on centralized stations is ideally suited for taking advantage of the economies of scale through large unit sizes and serve the needs of the industrial and urban sectors of an economy. Unfortunately, conditions in DCs have been such that in spite of huge investments made over several decades, the centralized systems have not been able to deliver the expected results, even to this restricted group of clients. The inherent shortcomings of a centralized power sector in most of the DCs today makes it unable to meet demands which continuously outstrip its generation, transmission, and distribution capacities. The power sector in DCs generally includes a rural electrification programme also, mainly to supply irrigation water for agriculture. These loads, which are individually very small, add up to a substantial total which is largely seasonal and creates large peak loads during irrigation seasons. Generally served from the tail end of transmission and distribution (T & D) systems, and in the absence of other types of consumers, the capital intensive power lines in rural areas operate at very low and, therefore, highly uneconomic average load factors. Additionally, these systems are largely responsible for the very high T & D losses of the power sector in most of the DCs. Taken together, these factors make the rural electrification programmes inherently unviable in commercial terms. The situation is made worse by a pricing policy for the agriculture sector which, dictated by political considerations, makes utilities sell power for pumping at well below their generation costs.

Other factors which lead to the unsatisfactory performance of the state-run power sector include:

- power tariff policies which do not permit differentiated rates for peak and off-peak consumption;
- very little demand-side management (DSM), leakages, and theft of power, sometimes on a large scale;
- over-staffing and other excessive overheads; and
- political and bureaucratic interference in decision-making and management.

As a result, most of the state electricity boards not only suffer from astronomical losses but they are also unable to meet their basic responsibilities, such as:

- reliable supply of specified quality to the industrial and urban sectors;
- reliable, timely, and adequate supplies to the agriculture sector;
- supplies to meet the development needs of the rural sector (affordable energy services for social needs such as drinking water, schools, hospitals, etc., and power for small, local enterprises); and
- minimum returns on investment (ROI)

Faced with such a situation, governments in DCs have started to tackle the problems of the power sector as a part of their broader economic restructuring programmes. Recent liberalization of economic policies in many developing countries includes the opening up of the energy and power sectors to local and foreign private ownership. Very attractive financial incentives and risk guarantees are being offered to foreign investors and IPPs to build privately-owned power stations, and, thereby, add to the generating capacity of the centralized sector. An underlying expectation is that the IPPs will also lead to an improvement in the overall performance of the power sector by subjecting the public sector utilities to market competition. However, given the commercial considerations, IPPs are unlikely to cater to the poor and disadvantaged sections of the population, especially in the rural areas

The role of IRPPs

Taking into account the situation outlined above and the requirements of villages and small towns in DCs, it appears logical to look for new solutions which can satisfy the needs of development while taking into account the demands of the Climate Convention. To expedite the process, any new solution would do well to take advantage of the recent policies introduced by DCs to attract IPPs, and use the instruments and mechanisms which have been created for promoting them. The IRPP proposed here is one such solution.

First, IRPPs work within the framework of the market, ensuring not only efficiency, but also an ability to expedite the acquisition of finances, managerial talent, and innovative technology that are not available to current programmes for rural electrification.

Second, it can, at the same time, contribute to important objectives for equitable development In comparison with conventional centralized systems, the IRPP's services are inherently more accessible to those who need, but who at present, do not have, electricity. Local control over its functioning also tends to increase the reliability of power supply and to reduce the dependence of the village community on outsiders.

Third, by reducing use of fossil fuels and virtually eliminating carbon emissions, it automatically meets important environmental goals.

Fourth, it can be innovatively structured to take advantage of new instruments created under the Climate Convention and other global treaties to promote sustainable development For example, an IRPP would be a prime candidate to receive capital investment for

any fund created through taxes on energy use or on CO_2 emissions. It would certainly be eligible for its own revenues from the reduction of carbon emissions under the proposed Joint Implementation projects of the Climate Convention. Other sources of bridging capital could include ethical or socially responsible investments from private investors, financial institutions such as the World Bank and the International Finance Corporation, pension funds, non-governmental organizations (NGOs), and others.

Given the structural changes taking place in the global economy, it is becoming obvious that new types of industrial production and new sources of purchasing power will soon have to be created in large numbers. Moreover, a highly inequitable world is not conducive to the kind of social stability needed for orderly growth of business activity. The industrial and financial sectors of the North and the South will, therefore, have, in their own interest, to respond to the power needs of the poor and rural sectors in DCs. Working actively together with the social sector, they can influence the official policies to support equitable new solutions which create a profitable role for themselves in a socially harmonious society. The process of establishing IRPPs need not, therefore, be left solely to politicians and governments. In establishing and structuring IRPPs, several economic, technical, and managerial factors have to be addressed. With appropriate choices of these, however, it is becoming clear from detailed calculations that they can be commercially quite attractive. Contrary to the assumption of many planners, the real cost of electricity from a centralized plant at the point of consumption is neither cheap nor economic. If the transmission losses and the cost of T & D systems are taken into account, it can be quite expensive, particularly in remote locations. Even if the rather substantial external (environmental, social, or long-term opportunity) costs of fossil electricity are neglected, mature renewable energy technologies can today deliver power at the end point of consumption in a village at a price which is competitive with the delivered cost of grid electricity (Figure 1). This can be achieved if the technological progress made in the renewable energy sector is combined with local involvement, innovative project packaging, and normal industrial inputs such as guarantees, operation, maintenance and after-sales services, training, etc. Unfortunately, the perception of this reality among politicians, policymakers, officials, and the industry is distorted today because the current sales price of electricity in a village is much lower than its real cost.

There are several mature and reliable technologies available for IRPPs. These include:

- biomass-based systems, including combustion, gasifiers, etc.,
- biogas systems;
- mini-hydro,
- wind generators and pumps,
- solar photovoltaics, and
- solar thermal

While most of the private sector investors in the power sector have a strong short term profit orientation, there is an interest among at least a part of the industry to get involved in futuristic solutions which show a chance of success in a medium term timeframe.

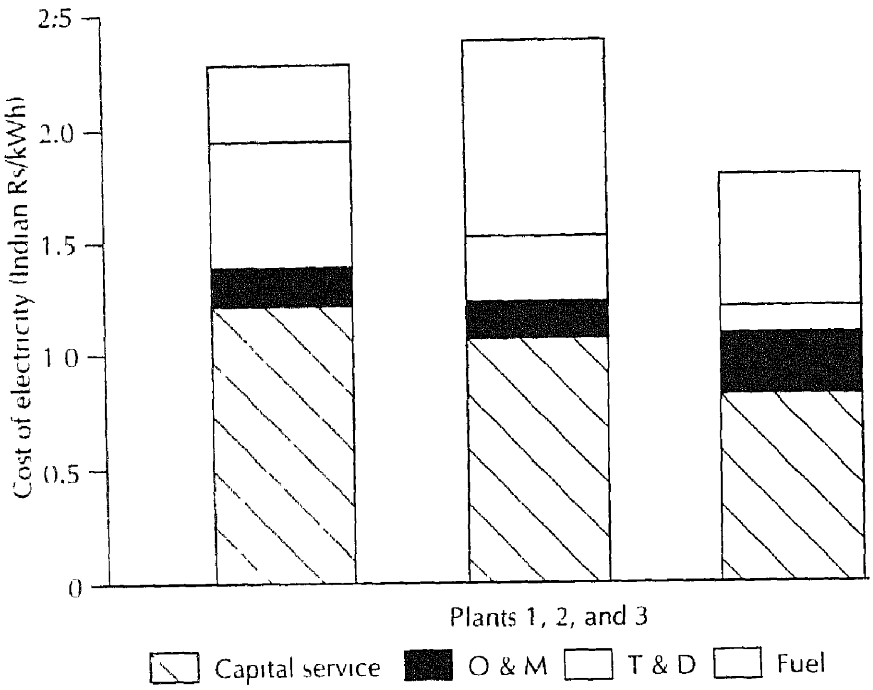


Figure 1. Break-up of power costs in a village; 1: a 210 MW minemouth coal IPP; 2: a 210 MW load-centre coal IPP; and 3: a 600 kW local biomass IRPP

There is certainly a willingness on the part of many governments and international funding agencies to provide direct and indirect incentives for clean energy and power projects, especially when they benefit the poor and the women. Such willingness needs to be practically harnessed in packaging IRPPs.

An analysis of past experience and the current market situation in villages and small towns, e.g., in India, shows that there is a considerable amount of unfulfilled demand for power among all sections of the population, and a not-inconsiderable purchasing power among a section of the local population such as larger farmers, shopkeepers, trading communities, small workshop owners, etc. At the same time, however, large parts of the local population in villages do not have the capacity to buy power at commercial prices and many village projects will, therefore, not be able to operate profitably in the first years of operation if power is sold only at commercial prices.

Advantages of IRPPs

Some of the advantages of building decentralized IRPPs are listed below

1 Their competitiveness increases with the unreliability of power supply from the grid which can be expected to grow for some time to come, especially as the power cuts in smaller towns and villages become more frequent, longer lasting, and less predict-

able. The substitute and emergency power supplies are expensive, inefficient, highly polluting, and full of complications.

2. They will accelerate rural development sustainably by creating markets for local resources, catalysing the creation of new jobs, social services, and the empowerment of the poor and the women, and establishment of conditions essential for orderly social change.
3. Being inherently profitable, they will spearhead the growth of renewable energy technologies and their large-scale production, leading to the transfer of technology to other sectors on a South–South and even South–North basis.
4. They can facilitate the introduction of a transitional energy policy during the next few decades to promote an increasing share of clean power systems in the national energy mix and reduce the growth rate of CO_2 emissions. They will thus partly compensate for the growth of CO_2 intensity in the industrial and urban sectors, and will help reduce the risks of climate change even as the development process gets accelerated and energy consumption increases in DCs.

Prerequisites for establishing IRPPs

To establish IRPPs on a large scale, the dual objectives of sustainable development and commercial viability will both have to be satisfied While this appears to be eminently possible in principle, satisfaction of both objectives will have to be demonstrated in practice, on the ground. The social and ecological goals of IRPPs will have to be achieved in a manner which is acceptable to promoters of sustainable development. And their technical, commercial, and operational viability will have to be demonstrated in commercially successful projects. Decision-making, managerial, and financial structures will have to be engineered to safeguard the interests of all the parties concerned· the community, the financiers, and the operational staff This will involve innovative approaches for integrating technical, social, financial, and ecological aspects, IRPP packages ultimately have to be attractive to prospective investors of diverse types without losing sight of the interests of local consumers While the projects themselves will be small, project definition, planning, and packaging exercises for the first phase of commercialization will require a considerable amount of sustained effort Suitable types of organizational frameworks will have to be evolved. These could involve various combinations of franchising, joint ventures with the community, and cooperatives. While many general policies for IRPPs may be universally applicable, many of the government policies and support mechanisms will need to be tailored to local conditions. Substantial inputs of time and effort will, therefore, be required for interaction with politicians, policymakers, implementors, as well as NGOs and the general public, for establishing an IRPP programme.

Types of IRPPs

To start with, two distinct types of IRPPs will have to be considered (i) commercial IRPPs; and (ii) semi-commercial IRPPs.

Commercial IRPPs

Commercial IRPPs would be appropriate for operation in small towns and larger villages which are already connected to the grid. In such communities, power connections to workshops, small-scale industries, shopkeepers, traders, and households already exist, but there is no reliable or regular supply of power. Market research has shown that a considerable amount of power can be sold to these groups of consumers. Once local investors find that a reliable source of power exists, new micro-enterprises (e.g., agro-based processes, workshops, and small factories) will be started, creating additional demand. New markets for small-scale irrigation, drinking water supply, schools, hospitals, and other social services also tend to emerge quickly. The economics of a commercial type of IRPP, on the same basis as the IPPs being planned today, is shown in Figure 2.

Typical investors in commercial IRPPs are likely to be:

- local, national, or foreign power/energy utilities;
- local, national, or foreign industries (big or small),
- local, national, or foreign development banks;
- pension funds, investment financiers, and banks; and
- private investors.

Semi-commercial IRPPs

A second type of IRPPs will require special structuring for villages which have neither a substantial existing load nor a large potential based on current earnings of the local population. Whatever small load that exists in such villages is predominantly for irrigation. A market for power has, therefore, to be created by working with other agencies to promote a number of integrated activities such as·

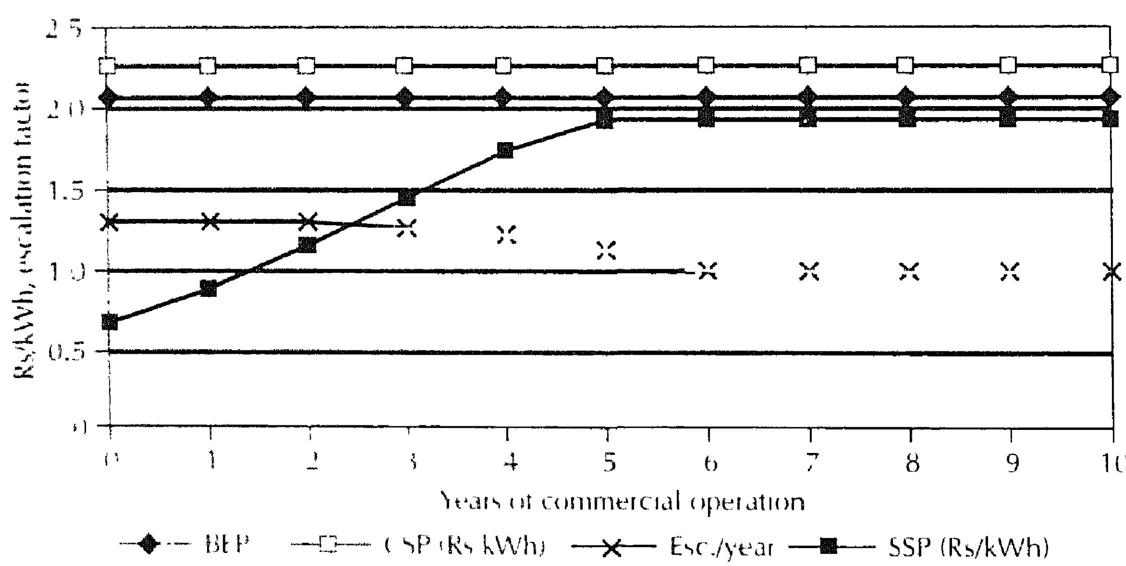


Figure 2 A commercial 600 kW IRPP: electricity sales prices for social sales of electricity by an IRPP, BEP: break-even price of electricity (Rs/kWh); CSP: commercial sales price of electricity (Rs/kWh); SSP: social sales price of electricity (Rs/kWh); Esc./year: escalation of SSP (percentage/year)

- creating new jobs through the power plant (supplying fuel, plant management, and operation and management)
- providing reliable and timely water supply services to increase the income from agriculture;
- networking with local investors, government, and financial institutions, and NGOs to catalyse the establishment of micro-enterprises such as agro-based industries, small factories and workshops, and creating new jobs

In such cases, where energy has to be used as the initial instrument to promote job creation and social development, the IRPPs will have to structure their financing to permit them to sell power at a price below the commercial prices for an identified section of the population for the first few years. As the paying capacity of this group of clients increases, the sales price can be regularly increased until the commercial level is reached. The financial packaging has to be designed to meet these losses of the first few years, which, for a typical plant, are shown in Figure 3.

Typical investors in semi-commercial IRPPs are likely to be:

- NGO funds;
- people in the towns and villages where the IRPPs are located,
- IPPs and power/energy utilities;
- local industries (big or small);
- local, national, or foreign development banks and funds; and
- international funding mechanisms such as the Global Environment Facility, funds created from CO_2 or energy taxes, Joint Implementation, etc

Conclusion

This concept paper is based on the conviction that new initiatives in national energy policies are most urgently needed to accelerate the social and economic development of the

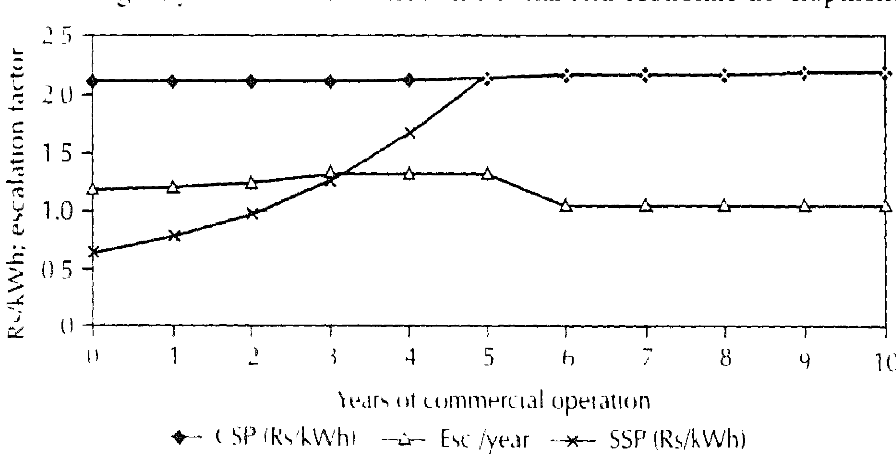


Figure 3. A semi-commercial 250 kW IRPP: sales prices of commercial and social electricity, Esc./year: escalation of social electricity price (annual factor)

rural areas in DCs. While giving the highest priority to the national development agenda, which demands a substantial increase in energy consumption for productive purposes, such initiatives can also be used to promote the goals of sustainability and to reduce the long-term risks of climate change. While long-term sustainability will depend upon what happens in the rural sector and in the small towns of the South, short-term sustainability will be determined by what the North, and the rich in the South, do about their consumption patterns.

No significant social and industrial development has taken place in large parts of the rural areas of the South. Can this be an opportunity for the DCs to show a different development path, which can gradually be extended to the North as well? A policy be made to meet the needs of the people and those of the climate agenda? Can IRPP be one of the instruments of a new development strategy which can simultaneously promote equitable social and industrial development, meet demands made by market mechanisms, and promote sustainability? We will never know if we do not try!

BIOMASS TECHNOLOGY IN BRITAIN AND EUROPE

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Introduction

In the distant past, biomass was one of the most important sources of energy in Europe. The start of the Industrial Revolution saw the use of charcoal and many large forests were destroyed, especially in Britain, due to this demand for charcoal. However, charcoal was eventually replaced by coal and then oil. Charcoal-making as a tradition eventually faded out in 1950s. There has, however, been a swing back again in the past few years. Biomass energy is becoming a potentially important source of energy, especially for electricity generation.

The context

Power production in Europe has traditionally been under the direction of large central producers. Most European countries have had nationalized industries in control of electricity generation, with large power stations based near the source of energy, which has usually been coal. The size of the power station has been generally increasing in size, with the closing of smaller stations (< 50 MW) often within towns, and the building of new out-of-town stations over 1 GW in size. The introduction of nuclear power has encouraged this trend, as nuclear stations work most efficiently, when they are big. The major change in the past few years has been the privatization of electricity generation, which has allowed small-scale producers into the market Britain privatized the state-owned monopoly – the Central Electricity Generating Board, in 1989. Other countries, such as Italy, have had some privately-owned electricity production for several years, but are proposing to privatize their state-owned utilities

In Britain, a political peculiarity has led to the government encouraging the production of energy from renewable sources, such as wind, water, and biomass, especially by small-scale entrepreneurs The Non-Fossil Fuel Obligation (NFFO) was set up in 1990 as a levy on fossil fuels that was designed to pay for the hidden extra costs of nuclear power. Since this did not look very good to environmentalists, the government was persuaded to include support for a small amount of power to be produced from renewable sources. NFFO proved much more popular than expected, with many entrepreneurs wanting to get into electricity production by this route. The presently stated government policy is to have 1500 MW of declared net capacity (DNC) from renewables by the year 2000.

NFFO works by asking for a series of bids by prospective electricity producers, tendering for the supply of a given amount of electricity, at a price above that of the average market price of electricity The bids are placed into certain bands according to the source of energy and a price is worked out for each band. The original cost for energy from wind was 11 pence per kWh, compared to a 'pool' price of around 3 pence. The extra price was made up by using money from the levy on electricity generated from fossil fuels by the major producers. The latest NFFO rounds meant that electricity distributors had to sign contracts with producers at their asking price, as long as it was below a cut-off price, which was assessed based on the average of the prices offered by all the bids. Wind energy technology has grown very rapidly in Britain under NFFO (Table 1) However, biomass energy, in different forms, has come a close second.

Other countries in Europe are following a similar trend, although in different ways. Many of the big state electricity corporations are being privatized, such as in Italy and Portugal. There is pressure from the 'green' parties to see more electricity generated from

TABLE 1
Progress of renewables under NFFO

Technology	NFFO 1 (1990) & 2 (1992)			1993 Actual (MW)	NFFO 3 (1994)		
	Number	MW	Price (pence/kWh)		Number	MW	Price (pence/kWh)
Wind	58	96.6	11.0	124.0	55	166	4.8
Hydro	38	23.0	6 0	1438.0	15	14	4 5
Landfill gas	53	84 0	5 7	77 0	42	82	3 8
Sewage gas	26	33.0	5 9	104.0	—	—	—
Municipal to industry	14	312.0	6 6	52.0	20	242	3.8
Farm wastes	—	—	—	25 0	6	104	5 1
Gasification	—	—	—		3	19	8 8
Others	8	76 0	5 9	0.3	—	—	—
Total	197	—	—	1820.0	141	627	—
Total (all three)					765	1251	

Note By February 1995, 340 MW from NFFO 1 & 2 were declared operational, and were generating electricity and selling it to the grid. The 'pool' price for electricity from fossil fuels floats between 3 and 4 pence per kWh

renewable sources, and some governments, such as that in Denmark, are providing strong incentives to build such plants. Denmark has the strongest wind industry in Europe, and the parts of most of the windmills built in the UK are manufactured in Denmark. The Danish government is keen to encourage the ownership of devices such as windmills by local cooperative groups and local government groups, as well as by individual businesses. Norway, Sweden, and Finland have a large proportion of electricity from renewable sources, since they have large hydro-electric resources. They also have a large timber industry, and have, hence, traditionally used wood as a source of fuel for domestic heating. They are, therefore, among the leaders in Europe in developing renewable energy technologies, especially from biomass. Most European countries now have schemes for encouraging the production of electricity from renewable energy sources, such as biomass, by paying a guaranteed premium price to producers.

Energy from wastes in the UK and Europe

One major concern of many local government groups in Europe is the disposal of waste. Western culture has been described as the 'throw-away society' and the use of packaging and disposable items has increased tremendously in the past 30 years. Local councils have been given the job of disposal of waste, but, in recent years, this has become a major problem. This could change, if this waste could be seen as a potential source of energy.

The most common way of disposing of waste is to put it in a hole in the ground. There are now well-defined rules as to how this can be done, as this approach is potentially a source of pollution. The hole has to be carefully made into cells lined with an impermeable membrane of clay or plastic, and each cell capped with a similar membrane. However, the waste ferments and produces biogas, as anaerobic bacteria begin to work. This biogas has been identified as a potential danger, as it can build up and explode. However, it can also be tapped and used as a source of energy, either in furnaces to produce heat for industries such as brick-making, or as a fuel for internal combustion engines generating electricity. In 1993, 77 MW of electricity was generated from landfill gas in the UK. There were 95 contracts under the first three NFFO schemes (1990, 1992, and 1994) generating a potential total of 166 MW.

The rest of Europe is behind Britain in the use of landfill gas. There is a keen interest in those countries that use landfill as the main way for the disposal of refuse, such as Germany However, many nations are looking for more effective ways of using refuse to generate energy.

Urban sewage also uses anaerobic fermentation to generate biogas, which can be used as a source of energy. A second source of energy for electricity generation from biomass under NFFO has been sewage gas. 26 contracts were signed for a total of 33 MW under NFFO 1 and 2 Some of the larger British water companies, such as Thames Water, now generate electricity from almost all of their sewage plants The third way of obtaining energy from wastes is by burning it Large scale incineration systems designed to burn municipal solid wastes (MSW) have been one of the largest sources of energy from biomass contracted under the NFFO scheme in the UK. A total of 554 MW from 34 contracts were agreed

The usual approach, called 'mass burn', is to put all refuse into the furnace including metals and glass. This means that much of the heat from the furnace is used to produce slag, a molten mixture of non-burnable refuse, which must then be cooled and used for landfill. A furnace designed to cope with mass-burn must be strong enough to withstand a large metal mass, such as an engine block, being dropped on it, from the waste feed system. Another problem with the mass-burn approach is that it tends to produce pollution from strong smelling and often toxic combustion products. Mass-burn incineration is a system which is, therefore, unpopular with the public.

The present emphasis in new schemes involving MSW is, therefore, on the separation of refuse into different components. There is a very strong move in Europe in general towards recycling, in which glass and metal are removed from the waste stream and reused. Glass can be remelted and formed into new containers. Metals can be recovered and used in alloys for making new products. Even plastics are being melted down and used to make new plastic products, such as fillings for insulation. The removal of these items from the waste stream means that less energy is required to burn the refuse.

A further level of separation removes the wet waste, such as food wastes, from the drier components, such as papers and cardboard. Wet wastes are difficult to burn, but can be used in an anaerobic digester to produce biogas. The dry wastes can be further processed, by densification to produce refuse-derived fuel (RDF), which can be used in conventional furnaces, giving a much better heat output. There are several such separation systems in Europe, in countries such as France, Belgium, and the Netherlands. The energy from biogas can be used to generate electricity from internal combustion engines and the heat from the furnaces can be used as process heat or to generate steam for electricity generation. While Britain is behind other nations in Europe in the anaerobic digestion of wet wastes, there is now a plant being built in Scunthorpe, which uses batch-type digesters with a high total solids content to deal with these wastes.

The most effective way to separate wastes into different streams is at source. In several countries in Europe, domestic waste collection now involves different types of waste being collected from different bins, often at different times. One bin might contain metal wastes, another glass, another plastic, and yet another paper. Putrescent refuse (which can be digested) is collected in yet another bin. The influence of the green parties and that of other environmentalists has meant that most people are prepared to change their habits and to place the different types of waste in the correct bins. However, this approach has led to the need for some local government groups to adopt fairly strict means to enforce the correct use of waste bins. The concept of the 'refuse police' has led to some rather odd court cases in countries such as Germany and the Netherlands.

The processing of industrial wastes to energy is somewhat easier than that of MSW, if there is a large enough quantity of a single type of waste that can be clearly categorized. The use of chicken litter being combusted in a steam-raising plant is one such example. There are now two such plants in the UK, one generating 15 MW in Suffolk, another now producing 13.5 MW in Humberside. In Europe, poultry for eating is often raised in large sheds that use wood chips on the floor. The wood chips absorb the chicken droppings and reduce smell and the danger of infection, but their disposal is difficult, as the wood takes time to decompose. These plants are located in regions of Britain where local farmers raise

large numbers of poultry and are keen to supply the company with used litter, so the cost of fuel is very low. Further plants are being planned in Britain and Italy.

Another agricultural waste that has a very high potential for energy production is cattle dung. However, the economics of biogas digestion seem to prevent its uptake in a large way in Europe, especially in the UK. There are farms in Denmark, France, Belgium, and Holland using biogas plants to produce biogas, which is used to generate electricity for on-farm use, but the technology has not caught on in a big way. The main reason seems to be the manpower required to feed the plant and to run the engine. European farming is heavily mechanized, as labour costs are high. A biogas plant that is automated enough to allow it to run with little supervision becomes very expensive. A plant that is less automated, though, costs a lot to run. The low ambient temperatures in Europe also work against the economics of biogas systems. An effective plant needs to be heavily insulated and heated, which puts up the capital cost of a farm-size unit.

There is growing interest in the use of biogas plants on a much larger scale to drive centralized electric generators that can produce 1 MW or more. The slurry would need to be loaded onto trucks to be transported from the farm to the central unit, but the costs involved seem to be lower than that of running separate farm-scale units.

The use of energy crops in the UK and Europe

The area that attracts the keenest interest in Europe is the use of energy crops. European farmers are becoming frustrated with the Common Agricultural Policy (CAP) of the European Union that restricts the amount of food crops that can be grown, so as to keep the price of food within Europe reasonably high. Food in Europe is subsidized, but if the production is excessive, too much money is required from the subsidies to pay for it. The result has been excessive amounts of stored food. Recent rules have restricted food production, so that these large excesses have been reduced, but at the cost of removing large amounts of land into 'set-aside' from agricultural usage. Farmers argue that the growing of fuel crops would help reduce the amount of carbon dioxide produced by using fossil fuels, while using their 'set-aside' land for the purpose for which it was intended.

The two crops capable of providing liquid fuels for use in transport are vegetable oil and sugar crops, which can be fermented to give ethanol. While the economics of these fuels look fairly weak, given the present price of fossil oil, many countries are keen to support a technology that could allow them to continue to supply transport fuels, even if fossil oil prices did suddenly jump. Many European countries are concerned that they are dependant on middle eastern nations for the supply of oil and would prefer to have the capability of an alternative, even if it might cost more.

Austria and France both have strong programmes developing the use of rapeseed oil for fuel The oil is esterified with ethanol or methanol to reduce its viscosity and make it more like diesel, so that it can be used in normal diesel engines Rapeseed is a crop that grows well in temperate climates and many European farmers are experienced in growing it for food purposes Although rape methyl ester costs twice as much to produce as diesel fuel, subsidies and taxes are used to ensure the prices to the customer is equal Other European

countries, such as Italy and Ireland, are also setting up programmes. One of the most attractive crops for farmers is short rotation coppice (SRC). Some strains of a temperate tree species, the willow (*Salix*), grow fairly fast, once it has been cut back after the first year of growth. Rather than growing as a single trunk, it throws up many thinner shoots which have a high productivity, up to 18 dry tonnes per hectare. The average growth rate is closer to 12 dry tonnes, the high growth rate strains tend to be susceptible to disease and pests. Once the root system of a SRC plantation is established, the shoots can be cut every three to four years and they will regrow again at the same rate. It is thought that a stand could last at least 20 years before replanting and could be cut for up to 50 years without loss of production.

Other tree species can be used for SRC, such as poplar and hazel, although they may need to be cut at longer intervals to get good growth. Such a plantation can be fertilized by sewerage, as there is no problem with pollutants such as heavy meals entering the foodchain. The shoots are normally cut during the cold season, as the species are deciduous and the shoots dry out and lose their leaves. This can be a problem in places where the ground is very wet, as it can be difficult to get heavy vehicles on to such ground.

When the sticks are harvested, they are usually about 5 mm in diameter. The sticks are usually chopped into chips about 5 mm long, using saws or heavy blades. The sticks can be cut and bundled in the field, where they are air-dried before being collected and chipped ready for use. Alternatively, they can be chipped during a single pass harvesting process and stored as chips. While the second approach is cheaper for the farmer, it means the wood must be stored and dried in chip form. The chips can be transported in standard trailers and can be moved between trailers and storage using standard grain lifts.

The use of chips for energy is an area receiving much attention in Europe at present. The chips can be burnt in small standard furnaces for heat production or for steam raising. Such plants are available commercially and used in countries such as Sweden and Finland, where there is a strong timber industry. However, the use of wood chips to raise steam for electricity production is considered uneconomic, as the price paid for the chips is much higher than that paid for refuse or coal. The most effective and efficient way of using wood for electricity production would seem to be through the gasification route, where the gas is used to drive internal combustion gas engines or gas turbines.

Downdraft fixed-bed gasifiers that can be used are commercially available in Europe, but the technology is limited to about 200 kW_e. This is too small to be considered a commercial size in the European context, although some farmers and small wood businesses are using them in countries such as France, Spain, and Greece. Updraft fixed-bed gasifiers can be made to a much larger size, but the gas from such gasifiers tends to be contaminated by too much tar for it to be easily cleaned for use in an internal combustion engine. Commercial plants of up to 10 MW heat are being used in Finland, but only for driving gas furnaces for heat generation, as the problem of gas clean-up has not been overcome. There are several approaches being made in the area of cleaning tar from the gas from updraft gasifiers. Technology is available from the oil industry for cracking the heavy oils in tars, either thermally or catalytically, but an effective economic system is not yet available. If a solution can be found to this problem, there is a huge potential market for 1–10 MW electricity generation from biomass.

Most of the European effort is now directed towards fluidized-bed gasification of biomass. There are several manufacturers of different designs of fluidized-bed systems in different European countries, especially Germany, Italy, and Sweden, as well as many more prototype systems in different research groups. The technology has been proved to work well, generating a clean gas that can be used in either internal combustion engines or in gas turbines. The major drawback, at present, is the relatively high cost of the system. Most analysts suggest that a fluidized-bed gasification system should be used to generate at least 30 MW electricity, using a combined-cycle gas turbine system, to be commercially and economically viable. Several such systems are in the planning stage, including one in the North of England under an NFFO contract.

There is a disadvantage of such a large-scale system, as large quantities of wood are required to keep it running. Where dedicated plantations of SRC or other forestry crops are used, or where there are large forestry processing plants, such as in Finland, Sweden, Norway, and in some parts of Germany, then transport costs can be fairly low. However, when local farmers are using their 'set-aside' land for growing SRC, the amount of wood available in a locality would be limited and wood would need to be transported longer distances to supply such a plant. Given that a transport distance of 25 km is acceptable, a typical gasification plant for a European situation should be of a size that will generate 5 MW_e. This suggests that more development should be done on updraft gasifiers to allow them to produce gas suitable for use in internal combustion gas engines.

Conclusion

Biomass has been an important source of energy for Europe and the UK in the past and could well be an important source of energy in the future. Energy from waste, especially MSW, is an important area for most European nations and there are several processes that are being used commercially on a large scale, such as landfill gas, sewage gas, and incineration. These processes could be very much improved if the refuse was properly separated into different streams, either at source or within the process. Energy from biomass crops is another area in which there is strong interest in many European countries. Even though present fossil oil prices mean that liquid fuels from biomass cannot compete on price, concerns about security of supply mean that programmes to manufacture and distribute such fuels are being set up in several nations.

Electricity generation from solid biomass, such as forestry residues and SRC, does look reasonably attractive, if the wood is gasified and used in internal combustion engines or gas turbines. Unfortunately, the present designs of gasifiers seem only to be economic if used at a scale larger than is practical in most situations in Europe. The development of an updraft gasifier that could be used economically and effectively at a scale of between 1 and 10 MW seems to be a very high priority

SUGARCANE AS A RENEWABLE ENERGY CROP

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Introduction

India is an energy-deficient country. The linkage between the energy availability and economic development is a well-known phenomenon. The per capita energy consumption in India is about one-fourth of the global average and the energy needs of various sectors are increasing rapidly. The conventional sources of energy are hydel, thermal, and, to a small extent, nuclear energy. The conventional fuels such as oil, gas, and coal cannot meet the increasing demand forever. In addition to the requirements of huge funds, the implementation of various projects to generate more electricity through the conventional means may have serious problems due to their adverse impact on environment.

In view of the above, great emphasis has been placed on exploring alternative renewable energy sources, such as solar energy, wind energy, biogas, etc. These renewable energy technologies use locally available materials, are suitable for decentralized applications, have low gestation periods, and are less capital intensive. The estimated potential is given in Table 1. Even if a small percentage of this vast potential is tapped, it would be possible to meet the total energy requirements of the country for years to come (Rajan 1995). Not many are aware that sugar industry could become the single largest source of non-conventional energy in India. As indicated in Table 1, it has the potential to contribute about 12% of the current power production at the lowest cost. Sugarcane has the remarkable characteristic of yielding green matter, energy, and fibre in a shorter cycle than any other plant species. This is the most efficient instrument for conversion of solar energy. The growing of cane – not for sugar but for energy for power and for ethanol – has been the most exciting development in the recent past. It is superior to crude or naphtha as a

TABLE 1
Estimated potential of non-conventional energy sources

Source/technology	Approximate potential/availability	Status of technology
Cogeneration (all industries)	15000 MW	Functional
Cogeneration (sugar mills)	6000 MW	Functional
Gasification	17000 MW	Functional
Small hydro	10000 MW	Functional
Solar energy	5×10^{15} kWh/year	Development stage
Wind energy	20000 MW	Development stage
Ocean thermal	50000 MW	Development stage
Sea wave power	20000 MW	Development stage
Tidal power	9000 MW	Development stage

Source. Rajan (1995).

feedstock, for it is renewable and ever replenishing. It is derived from an inexhaustible source – the sun – which the tropics and the sub-tropics get plenty of.

Sugarcane: an energy crop

Photosynthesis is one of the most efficient natural processes for the conversion of abundant solar energy into biomass. In this respect, the sugarcane plant holds a unique position in the family of annual crops. This is the only crop which is endowed with the highest solar energy conversion efficiency for biomass and can be rightly named as a vast storehouse of fibre, food, fuel, fertilizer, and chemicals. One hectare of land can annually produce about 10 tonnes of valuable fibre for paper, 10 tonnes of food products including sugar, a kilolitre of alcohol, and 2 tonnes of fertilizers, provided the raw material is processed in a more efficient manner.

The by-products of the sugar industry, bagasse and molasses, are very valuable. Good quality paper can be produced from bagasse. It is also a captive fuel for generating steam and surplus power. Molasses is used for the production of alcohol, and also as a feed for alcohol-based organic chemical industries. Alcohol has been used as a substitute for petrol in automobiles. India is a world leader in sugar production, and also tops the world in the production of chemicals from alcohol. The only plant in the world for the production of synthetic rubber from alcohol is located in India at Bareilly, Uttar Pradesh Sugarcane, therefore, is a wonderful crop, which uses solar energy to the maximum extent and provides a variety of food and chemical products, it can also be used to generate electricity through cogeneration

Cogeneration

Cogeneration is the simultaneous generation of power and steam Most process industries consume energy in two forms, namely, steam and electricity Steam is mainly required for

process heating. The electric power is used for driving various machinery and electrical heating. Generally, electricity is purchased from agencies like the state or central electricity boards. However, most industries also have their own steam boilers, fired either by fuel oil, coal, natural gas, or agroresidues. The concept of cogeneration can rightly be introduced at the design stage of all such units that require large inputs of steam and power. The steam must be generated in high-pressure boilers and then expanded in a steam turbine to generate electric power. The low-pressure steam may be used for process heating. Figure 1 shows a schematic diagram for cogeneration. Recently, Mahajani (1990) discussed the salient design features of a cogeneration plant. Gehlawat (1993a; 1993b), Verma, Khattar (1990), and Sarin, Agarwal (1995) have discussed the importance of cogeneration in sugar industry.

Bagasse is used as fuel to generate steam as well as power. No external fuel is required. Hence, sugar mills are ideally suited to adopt the cogeneration technology. Bagasse is a clean fuel. Consequently, cogeneration from sugar mills would produce less emissions of carbon dioxide, other gases, and particulate matter, making it environment-friendly. Further, sugar mills are located in rural areas and are widely distributed throughout the country. The surplus power thus produced by sugar mills in rural environment should prove a boon for the surrounding rural areas which had remained neglected so far. These advantages of cogeneration namely, an improvement in power supply, decrease in transmission losses, and generation by widely dispersed sugar mills near the consumption areas (rural and farming communities), are indeed noteworthy.

Cogeneration is not a new concept in India, as sugar mills have been generating electricity for many years for their captive requirements. Small countries like Hawaii and Mauritius meet over 50% of their power needs from sugar industries through cogeneration (Punnathara 1991). The overall efficiency of some cogeneration systems, according to one estimate, can be in the excess of 80% as compared to the typical 35% of a power utility based on conventional means. So far the sugar mills have not considered generating sur-

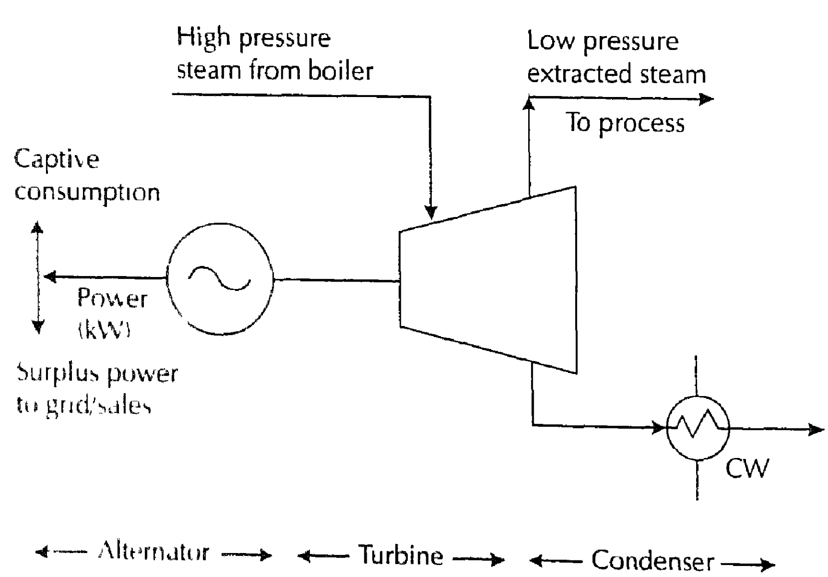


Figure 1. Schematic diagram for the cogeneration industry

plus power at a fraction of the investment cost of a new power plant and selling it to the grid According to a recent estimate, the potential of cogeneration in the country by sugar and other industries, through the use of biomass, biogas, bagasse, and diesel-fired systems, is about 17 000 MW (Rajan 1995). About 30%, that is 6000 MW, could be provided by the sugar industry alone at a very low investment.

Unlike other sources of non-conventional energy which are still at the development stages (Table 2), the cogeneration method is a proven and mature technology There are positive indications that high pressure boilers (above 65 kg/cm^2 rating) may be manufactured in India soon (Sekar undated; Aga undated).

It will be in the larger social interest to promote the setting up of cogeneration facilities at all new sugar mills, and at those mills which are to undergo substantial expansion and modernization. Adequate incentives, including low cost funds should be provided to the industry for this purpose. While commending cogeneration as an efficient and economic source of additional energy, the World Bank has indicated its willingness to provide credit for any project that may be recommended by the state or central governments (Dharamrajan 1992).

The report by Sarin, Agarwal (1995) shows cogeneration in sugar mills to be commercially highly attractive In a typical example for a 3500 tcd mill, a double extraction condensing turbine of 22 MW rating, working at 64 kg/cm^2 pressure on mill bagasse, is noted to generate 12 7 MW power per day during the crushing season. During the off-season, the same turbine when run fully on the condensing mode will generate 22 MW of power The captive power consumption during the season is estimated to be 5 MW whereas it will be 2 MW during the off-season. Thus, after meeting captive power needs, this cogeneration plant will produce surplus power of 7.7 MW during the crushing season and 22 MW during the off-season. The incremental cost of such an installation for a 3500 tcd capacity is found to be Rs 255 million If instead, boiler pressure of 85 kg/cm^2 is used at some incremental cost, the total power generation capacity could go up to 26–30 MW with tremendous economic advantages.

TABLE 2
Installed and projected capacity for power generation

Year/period	Installed capacity (MW)	Plant/load factor [average (%)]	Additional during Eighth Plan (MW)	Effective production (MW) (approximately)
1992/93 (all forms)	70000	54	—	38000
Eighth Plan Period				
Hydro	—	—	9000	
Thermal	—	—	20500	
Others (non conventional)	—	—	500	
Total	70000	54	31000	54000

Note The potential of power from sugar mills through cogeneration = 6000 MW

It is noted from the above analysis that the modern cogeneration plants at sugar mills could be installed at a fairly low cost of about Rs 20 million per MW as compared to about Rs 40 million per MW for independent power plants based on, say, coal as the fuel. Moreover, the gestation period is low and bagasse is the captive fuel. Hence, the cost of power is the lowest. As shown by Sarin, Agarwal (1995), at the current rate of Rs 2.25 per unit as agreed by most state electricity boards, the revenue generated is so good that the payback period works out to be as low as two years. Obviously, cogeneration for sugar mills could be a money spinner.

It is indeed good to note that the government has recognized the potential of cogeneration in the sugar industry and is encouraging its development. It is also good to note that several progressive sugar mills in South as well as in North India have already set up modern facilities to generate surplus power from bagasse. Several projects are under implementation and many more will come up in the near future. Projects aggregating to about 40 MW surplus power generation have already been implemented while other projects aggregating to about 250 MW surplus power generating capacity are reported to be under various stages of finalization (Rajan 1995).

It is noted that through the cogeneration technique sugar mills have a potential to supply about 6000 MW surplus power at the lowest cost. Since sugar mills are located in rural areas, it is logical to suggest that this surplus power may be supplied to the rural consumers. It is good to note that many state governments have allowed the supply and sale of electricity within a radius of 5 km by the mill's own transmission lines. It will be in the social good if the state governments increase the scope as under (Sarin, Agarwal 1995).

1. The working range for selling power by sugar mills may be increased radially by 25–30 km in conformity with the cane area reserved by the cane commissioners.
2. The mills may be allowed to sell the surplus power to any industry/private consumer within this working range.
3. The mills may also be allowed to sell the power to farmers and cane growers and they may recover the electricity charges from the respective cane growers from their sugarcane payments. This will result in healthier and stronger relationship between sugar mill and the cane growers.
4. Although the total cost of transmission and distribution lines shall be borne by the sugar mills, the respective SEB may be paid mutually agreed charges per unit of power, if their transmission and distribution system is used instead.

Conclusion

Sugarcane is a renewable energy crop. The sugar industry could be the biggest source of non-conventional power supply through the cogeneration technology. Clear policies should be laid down for supplying surplus power from sugar mills to the consumers in the command areas of the respective sugar mills through the existing state/central transmission systems. This will ensure an uninterrupted power supply to the consumers within the command area of these sugar mills. This will also, therefore, promote speedy development

of agriculture and rural industries Such development will change the rural scenario from the present state of extreme poverty to a state of plenty and prosperity. Therefore, top priority must be given to all proposals for the modernization and expansion programmes of sugar mills with cogeneration facilities. Setting up of integrated sugar complexes, including a distillery and a paper mill, should be promoted (Gehlawat 1990) They are environment friendly and will regenerate their resource, that is, sugarcane, annually through surplus power for agriculture and treated effluent water for irrigation (Subrahmanyam 1992; Gehlawat 1992).

References

Aga R D. Undated. Private communication Pune Thermax Ltd

Dharamrajan S 1992 Role of cogeneration *The Times of India*, 11 November 1992

Gehlawat J K (ed) 1990 *Modernisation of Indian Sugar Industry* New Delhi Arnold Publishers (India) Pvt Ltd

Gehlawat J K 1992 Resource regeneration from effluents of agroindustries *Proceedings of the Seminar on "Effluent Treatment and Pollution Control in Sugar and Distillery Industries* IE (I), 8–9 October Hyderabad

Gehlawat J K 1993a Sugar industry – a unique and powerful source of non-conventional energy in India *Chemical Industry News* 38(5) 507

Gehlawat J K 1993b Sugar industry may become the biggest source of non-conventional energy through cogeneration *Alternate Sources of Energy*. New Delhi. Allied Publishers

Mahajani V V 1990 Planning and design of cogeneration units IE(I), JI-CH, 71 (10)

Punnathara C J 1991 Proposal to generate power from bagasse *The Times of India*, 25 September 1991.

Rajan T P S. 1995. Eco-friendly fuels from perennial and renewable resources – Indian scene *Chemical Weekly* 40(11), 61

Sarin J N, Agarwal U K 1995 Cogeneration – The real money spinner *In Proceedings of the 57th STAI Convention*. pp 479–492

Sekar R Undated Private communication Tiruchirapalli Cethar Industries Ltd

Subrahmanyam P V R 1992. Cane sugar industry-based environmentally balanced industrial complex *Proceedings of the Seminar on Effluent Treatment Pollution Control in Sugar and Distillery Industries* IE(I), 8–9 October Hyderabad

Verma A K, Khattar H K. 1990 Economics of cogeneration in sugar industry. *In* Gehlawat J R (ed) *Modernisation of Indian Sugar Industry*. New Delhi· Arnold Publishers (India) Pvt Ltd

SUSTAINABLE USE OF SUGARCANE AS A SOURCE OF FOOD AND FUEL IN SMALL AND MEDIUM VILLAGES

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Introduction

The revised population projections of the UN estimate that world population size in the year 2050 could be around 6–8 billion depending on the fertility rates (CRSL 1993). Further, about 60% of the world population would be living in urban areas. If the above are taken into account, a large number of villages in India would almost *disappear* (will not have any sizeable population). However, this depends on the long-term urban and rural and human resource development policies and the availability of water.

For economic reasons, small villages of the future could be presumed to be those with a population of around 1500 and a medium village to have a population of 3000. People living in small villages would depend mainly on land-based activities, while those living in medium villages would depend on non-land-based activities.

Further, urban areas would be accommodating nearly 50% of the total population. Various models of development of providing basic infrastructure facilities for these small and medium villages on sustainable basis will have to be worked out. In the present paper, a model for providing energy for small and medium villages is proposed.

Sugar industry

India is one of the largest producers and consumers of sugar in the world [during 1994/95, India produced about 14 million tonnes (mt) and consumed 11 mt of sugar]. For historical

reasons, more than 50% of the nearly 500 sugar factories have capacities less than 1500 tonnes of cane per day (tcd), and, at present, not more than 100 factories have capacities exceeding 2000 tcd. Out of these, only a few factories have started cogeneration. Further, a very large number (more than 2000) of cane crushers have capacities ranging from 40 to 100 tcd in India. This may be contrasted with sugar factories in developed countries where capacities exceed 10 000 tcd. Any attempt to follow developed countries to increase the capacity to gain economic benefits would not be sustainable (Vijayakumar 1995). Thus, instead of having a centralized production of energy, a highly distributed production of energy becomes very important. The sustainable model proposed would indicate proper use of sugarcane by emphasizing important biological properties of sugarcane as a source of food and fodder

Even in the development of animals and plants, it may be noted that after millions of years of experimentation, though nature even evolved specialized organs for circulation, respiration, filtration, etc , it did not evolve a centralized organ for generation of energy. And this clue from nature requires to be properly understood by all those concerned with sustainable development Books and papers listed in the references mostly concentrate on the use of sugarcane in large quantities A major number of fuelwood forestry programmes, because of long gestation periods, low dry biomass yields, and competition with food crops in getting good land and adequate water have failed to make any major dent in solving fuel problems faced by villagers Most of the biogas programmes benefit only those owning cattle, and large-scale biogas projects depending mainly on cattle dung require coordination and cooperation of a quality that is not easily achievable. Sugarcane, because of its higher photosynthetic efficiency, is one of the best converters of solar energy. Most parts of India receive good sunlight almost throughout the year There are certain high fibre-producing varieties that have been ignored due to their low sugar content. Such varieties can produce as much as 40 to 50 tonnes/ha/year of dry mass compared to 5 to 10 tonnes/ha/year available from other agricultural and fuelwood plants. The theoretical potential of sugarcane dry mass is about 130 tonnes/ha/year

Sugarcane as an energy crop has not received much attention. Even assuming only 10% of the dry mass produced would be available for fuel purposes, one hectare of sugarcane gives more dry mass than one hectare of other fuelwood plants. This would be in addition to the main product: sugarcane juice. Considering the energy demand, the day may not be too far, when sugarcane would be mainly grown to get energy as a main product and sugar as a by-product. Most of the sugar technology institutes see sugarcane only as a sugar-producing plant, but proper variety selection and management can lead to unbelievable results

Generation of energy by burning bagasse can be less sustainable compared to generation through biogas plants However, large units burn bagasse for cogeneration, losing biomanure and other useful by-products As technology is available to convert bagasse to biogas and the time to commission plants of fairly large size is comparatively less, this may provide a better alternative

Proposed model

India receives excellent solar insolation across the country. As sugarcane is one of the best converters of solar energy, a geographically-diffused industry can capitalize on the available supply of renewable energy. Fibre-rich sugarcane varieties must be promoted as an energy crop to become commercially viable.

In the initial stages, it is proposed to take up a 1 ha sugarcane plantation for a village with the population of 1500. With the currently available fibre-rich variety, we get about:

- 100 tonnes of sugarcane (potential 400 tonnes);
- 50 tonnes of sugarcane juice containing about 10 tonnes equivalent of sugar (potential 200 tonnes of sugarcane juice containing about 40 tonnes equivalent of sugar); and
- 30 tonnes of dry mass (bagasse; potential 120 tonnes).

A typical village with 1500 people has about:

- 300 families;
- 60 very poor families; and
- 400 children in the age group 5 to 15 years.

The benefits that can be given if the current yield is assumed include these listed below.

1. Each child in the 5–15 year age group, on an average, gets about 1250 ml of sugarcane juice containing about 125 g of sugar (giving about 500 calories of energy) for 300 days in a year.
2. Each of the very poor families gets about 3 kg of dry mass per day for six months in a year; this dry mass can be directly used in improved stoves, or in a biogas plant (individual or community type).
3. Eight persons are continuously employed through the year who would be harvesting and extracting cane juice using hand-operated crushers, and also transporting manure from biogas plant back to lands from where the sugarcane was harvested.
4. Even though the requirement of water appears to be high for cultivating sugarcane, setting apart small lands with an assured water supply for sugarcane (which give much higher yields) would mean a much better way of utilizing the scarce resources of water.

It may be noted that all these benefits can be provided utilizing the resources now being spent on various fuelwood programmes. And, once the model becomes acceptable, it can be extended to medium villages. If we promote fibre-rich varieties having higher biomass potential, the benefits that can be given would not be difficult to imagine.

References

CRSL. 1993. Congressional Research Service Library of Congress on *International Environment Briefing Book on Major Selected Issues.* Prepared for the Committee on Foreign Affairs US House of Representatives. Washington, DC. Congressional Research Service Library.

Vijayakumar M N 1995 Sustainable use of sugar cane in small and medium scale units Project prepared at the Center for Energy and Environment, University of Delaware, USA

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